An Integrated BIM Framework to Support Facility Management in Healthcare Environments

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ABSTRACT

The quality of healthcare environments has been linked to patient safety, patient and staff stress, clinical output, and patient outcome. As part of maintaining the physical environment within the healthcare settings facility managers need to ensure that complex systems are working properly. Facility management tasks need to be completed with minimal interference with clinical services. This is often difficult to do because facility information is often stored in multiple systems and may be inadequate and incomplete. Communication and exchange of information throughout the lifecycle and throughout the operational phase of the building is fragmented. Relevant information and effective facility information management are important for efficient operation and maintenance of the facility. It is even more important when systems are being constantly upgraded and renovated due to new technologies and for the need for facility managers to do more work with fewer resources.

This research is examining the link between facility management and clinical activities, especially in terms of information exchange and management. A framework is proposed to help facility managers more efficiently manage healthcare facility information. Case analysis was completed on facility related patient safety events to determine the types of information needed and exchanged through the event's response by facility personnel. The information was then organized into a product model and ontology to help capture, manage, and retrieve the information. The goal of the research is to offer a method of storing healthcare facility information in an efficient and effective manner to support facility managers in their response to patient safety events.

This dissertation outlines the objectives of this research and the methodologies used in the case analysis. The development of the product model and information exchanges identified is also discussed. Lastly, conceptual model for a prototype was developed and is presented to demonstrate how the product model and ontology can be used to allow the user to query information and interact with the system.

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1. INTRODUCTION

1.1. Background

The *lifecycle* of a facility can be defined as the time period involving various phases from inception to termination. The National Science Foundation (NSF) defines lifecycle phases as: (1) Concept, (2) Development, (3) Implementation, (4) Operations & Maintenance, and (5) Renewal or Termination (NSF, 2003). Within each of these phases are a series of related operations or project processes. Using NSF definitions, Figure 1 shows a graphical depiction of project lifecycle phases including project operations/processes.

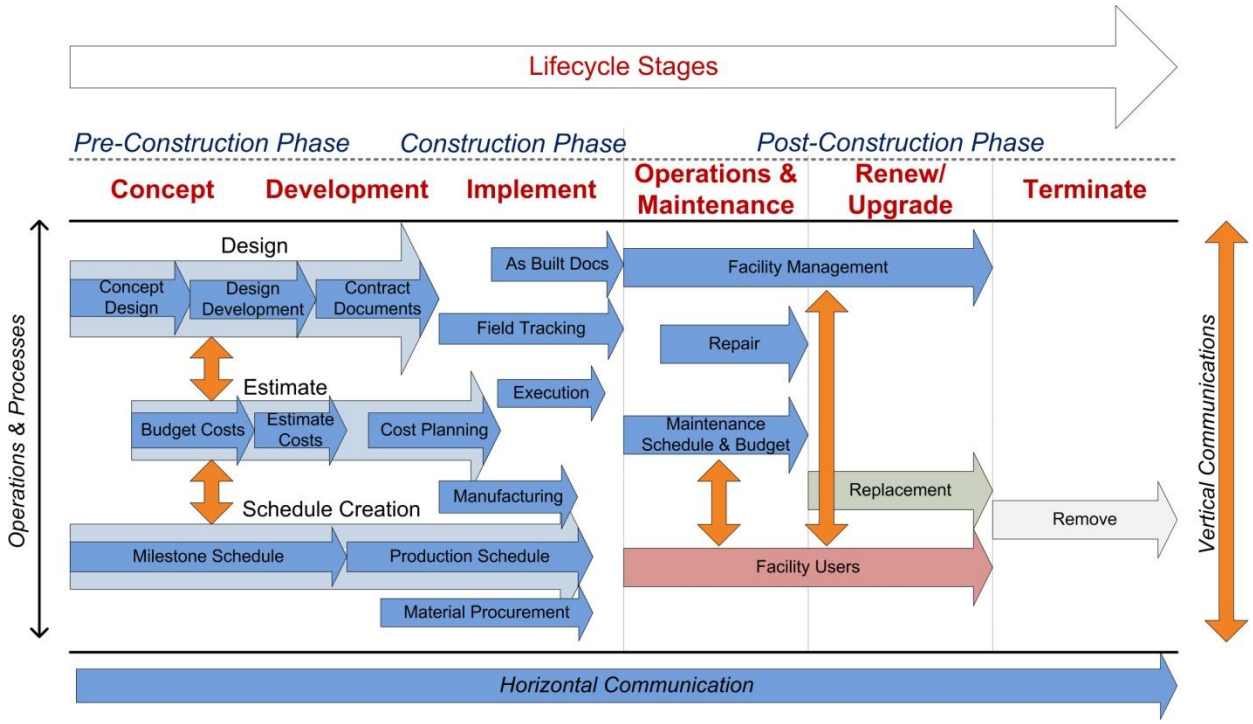

Figure 1: Project lifecycle with sample of phases

The phases depicted in Figure 1 are not always distinct and the amount of overlap and integration between players usually depends on the project delivery method chosen (e.g. traditional design/bid/build vs. design/build). Project information typically flows from left to right through the lifecycle phases with one process leading into another. Information generated during the pre-construction and construction phases includes plan and specification documents, schedules, estimates, contractor notes, and the like. During the operation and maintenance, renewal, and termination phases facility information, consisting of renovation drawings, maintenance schedules, upgraded systems, and contractor/supplier information, is added. This flow of information from left to right in Figure 1 represents the horizontal communication that occurs across the project phases.

Communication also occurs vertically between concurrent processes and within phases. Examples of this may be design influencing estimates and schedules, or schedules influencing material procurements.

Information Management and Communication

Lifecycle management is defined as the process that incorporates all phases of a project from design through facility management with information exchange and communication between all parties (Guo et al., 2008). No matter the amount of overlap, the information exchange through the lifecycle phases needs to be properly managed. Proper management of information exchange is not just making sure that information that is created by one party is transferred to other parties, but that it is documented and stored in an adequate format and at the proper level of granular detail to allow ease of retrieval to support downstream operations/processes.

Poor management and exchange of information between project participants within and across phases lead to wasted time and money during a project. The origins of poor information management can be traced to inadequate coordination caused by information that is inadequate, insufficient, inappropriate, inaccurate, inconsistent, late, or a combination of these (Gallaher et al., 2004). Despite advances in information management, handling, storage, and exchange techniques, these issues of poor information coordination still occur. Improving communication is the key factor to the success or failure of effectively and efficiently operating, managing, and maintaining a facility (Deng et al., 2001; Eastman et al., 2008; Gallaher et al., 2004).

One possible solution to improving the communication and exchange of information within and across phases of the lifecycle is through the use of an ontology and Building Information Modeling (BIM). An ontology helps to define a language to represent a knowledge base of information that is interpretable by a computer (Gruber, 1993). BIM, as an idealized process, is the creation of a model to support exchange of various types of information to multiple users involved in the design, delivery, and operation of a facility through a data rich, object-oriented, intelligent and parametric digital representation of the facility (Eastman et al., 2008). Beyond delivering the facility, integrating BIM into the delivery process could allow the owner to better utilize the model for management, maintenance, remodels, and additions of the facility during the facility management processes (Ashcraft, 2007). When BIM is utilized as the center of communication for all parties involved in a facility's lifecycle, there can be improved communication, less rework, a greater information exchange fluidity, and improved information management. Using an ontology with BIM can help to better manage the flow of information by capturing and formatting information as well as intelligently retrieving and querying information stored within the BIM. Ideally, BIM offers an open and collaborative working environment where information is freely exchanged

throughout the facilities lifecycle. In practice, however, BIM's use as a communication tool is mostly as an aid to estimating, visualization, and trade coordination. During design and construction, models may be exchanged, but a large amount of the work is unusable due to lack of consideration to other downstream phases and usually new models need to be recreated.

Facility Information Management

The FM phase is the longest of a facility's lifecycle with a total cost that greatly exceeds the design and construction phases (Fuller, 2010), but it is one of the most disconnected phases from the rest of the facility lifecycle (Geodert and Meadati, 2008). Information from earlier phases that is turned over to FM is often not complete, housed in multiple systems, or has no cohesiveness, making it difficult to use for completing FM processes (Geordert and Meadati, 2008).

BIM's continual and cohesive use throughout the lifecycle of the project is inhibited because the different phases and processes of the lifecycle often involve different teams with poorly established communication and resistance to open information exchange (Ashcraft, 2007; Ospina-Alvarado and Castro-Lacouture 2010). BIM is a tool that can be successfully used by FM personnel if it is developed properly to include relevant upstream process information that support downstream FM processes. However, the actual use of BIM during the FM phase is difficult because FM processes are commonly disconnected from the rest of the facility's lifecycle (Goedert and Meadati 2008).

Healthcare Environments

Facility critical buildings, such as hospitals, rely heavily on FM personnel to properly maintain the facility in order for the organization to operate efficiently. Patients and staff safety rely on effective maintenance and operation practices. Clinical and FM personnel are also under staffed and under resourced and are constantly looking for ways to more efficiently complete needed tasks by doing more work with less personnel. From the facility management point of view, a hospital is a complex and dynamic system in which all spaces, building components and assets are related to each other. There is continuous movement of people and goods between spaces. This leads to a close link between the healthcare facility information and facility's content. FM's ability to support the healthcare activities by providing a safe, healthy, clean, and operable facility influences the efficiency and effectiveness of the clinical operations. In order to effectively complete their job, FM personnel need quick access to the correct information. Delayed actions, such as not knowing the location of a shutoff valve to a leaking system can lead to increased damage, increased danger to patient and staff safety, and a larger environmental hazard risk. Current and updated information about the facility and other related clinical activities is important to make in-time critical decisions in healthcare environments. Accommodations for

work have to be done while the healthcare facility is still in operation, amplifying the need for adequate information to contain and eliminate potential hazards that put the building occupants at risk.

The function of the physical environment is important to providing quality care and ensuring patient safety within a healthcare setting. Proper design, maintenance, and care of the physical environment helps reduce patient and staff stress, improve recovery outcome, and overall healthcare quality (Ulrich et.al., 2004). Better indoor working environments have been linked to better productivity (Clements-Croome, 2003), which can lead to better quality of care. Similarly, hospital construction and renovation activities are identified as the sources of airborne infection outbreaks due to dust or particulate generation (Humphreys et al., 1991; Iwen, et.al., 1994; Loo et al., 1996; Opal et al., 1986; Oren, et.al., 2001). Guidelines exist within the industry, such as those from the U.S. Department of Health and Human Services (Sehulster and Chinn, 2003), and other design standards, to help facility managers ensure the environment of care is safe.

Healthcare environments are constantly changing with new renovations to accommodate new standards and new technologies. Ongoing projects of various sizes can become difficult to keep track of and knowing what work is being done in what areas and how clinical processes are affected can be a difficult task. BIM can serve as a central information capture and exchange point to track maintenance requirements, air quality issues, work orders, renovation, and water incursion/mold problems. BIM, with properly structured information, can be used as a tool to store all lifecycle process information (horizontal information exchange) and can also enhance communication and information exchange during the operations phase of the facility's lifecycle between healthcare and facilities personnel (vertical information exchange). Healthcare information consists of the different healthcare regulations and codes, as discussed in the literature review, and clinical related information such as personnel on duty, protocols, and procedures.

1.2. Statement of Problem

Healthcare facility managers are tasked with operating and maintaining complex systems while allowing continued clinical services and keeping a safe environment for patients, staff, and visitors. For effective and efficient management of the facility, information needs to be readily available in a format that can support the activities that are taking place. Needed information comes from two directions, (1) horizontally, across the lifecycle from the design and construction phases and (2) vertically, from within the concurrent clinical operations.

The operations and maintenance phase of the facility's lifecycle is often disconnected from the design and construction phases creating a lack of clear and/or continuous communication. There is little

consideration given to the format and structure of the information created during each process to allow for supporting downstream processes. This leaves FM with information that is often inadequate, hard to sort through, or incomplete making collaboration between parties difficult to accomplish (Deng, et.al., 2001; Geordert and Meadati, 2008). To further complicate things, communication with clinical groups is often non-existent and quick access to needed information is not always available. Coupling these factors with the constant need for FM to do more with less resources, personnel, time, and money adds to the need of a structured information support system for FM processes.

Problem Statement #1: Horizontal Information Disconnect: Information generated from upstream processes and phases of a facility's lifecycle is fragmented and does not properly support facility management processes.

Information exchange between Facility Management (FM) and earlier lifecycle phases is not properly integrated. Information is fragmented between players. BIM technologies and IT solutions currently used by the industry do not allow for full collaboration and information exchange in a coherent manner to support FM groups. Renovation and maintenance schedules add to the amounts of information that are scattered among FM groups. This fragmented information makes scheduling maintenance and responding to unplanned crisis events difficult and inefficient. The inefficiencies of finding the correct information in a timely manner add to the workload of an under-resourced staff. The origin/source of needed information in the required formats need to be tracked and captured through an ontology-based BIM to help make FM processes more efficient.

Problem Statement #2: Vertical Information Disconnect: There is an information flow disconnect within the operations and maintenance phase of the facility's lifecycle between facility management and clinical operations.

Facility Management (FM) and clinical personnel are disconnected with minimal communication and information exchange. Informed FM in healthcare facilities is critical to patient safety and wellbeing. FM groups are currently disconnected from relevant clinical personnel during normal operations. The information technology systems used by FM and Clinical personnel do not communicate. Information exchange and coordination of work are limited most often to phone calls, email, and pages or require personnel to leaf through large piles of documents. The information is not centrally stored and located to allow for efficient and effective reference. Fragmented information from the different groups makes it difficult to support effective decision making. Managing these situations currently requires persons of knowledge to be available and involved. The knowledge and experience of such individuals are lost if those individuals are unavailable or need to be replaced.

Problem Example

A water incursion in the operating suite of a hospital can demonstrate the amount of information that FM staff need to reference from throughout the lifecycle of the facility as well as the healthcare regulations and clinical protocol that are in effect. Figure 2 shows the pieces of information that are either referenced or created during a water incursion event.

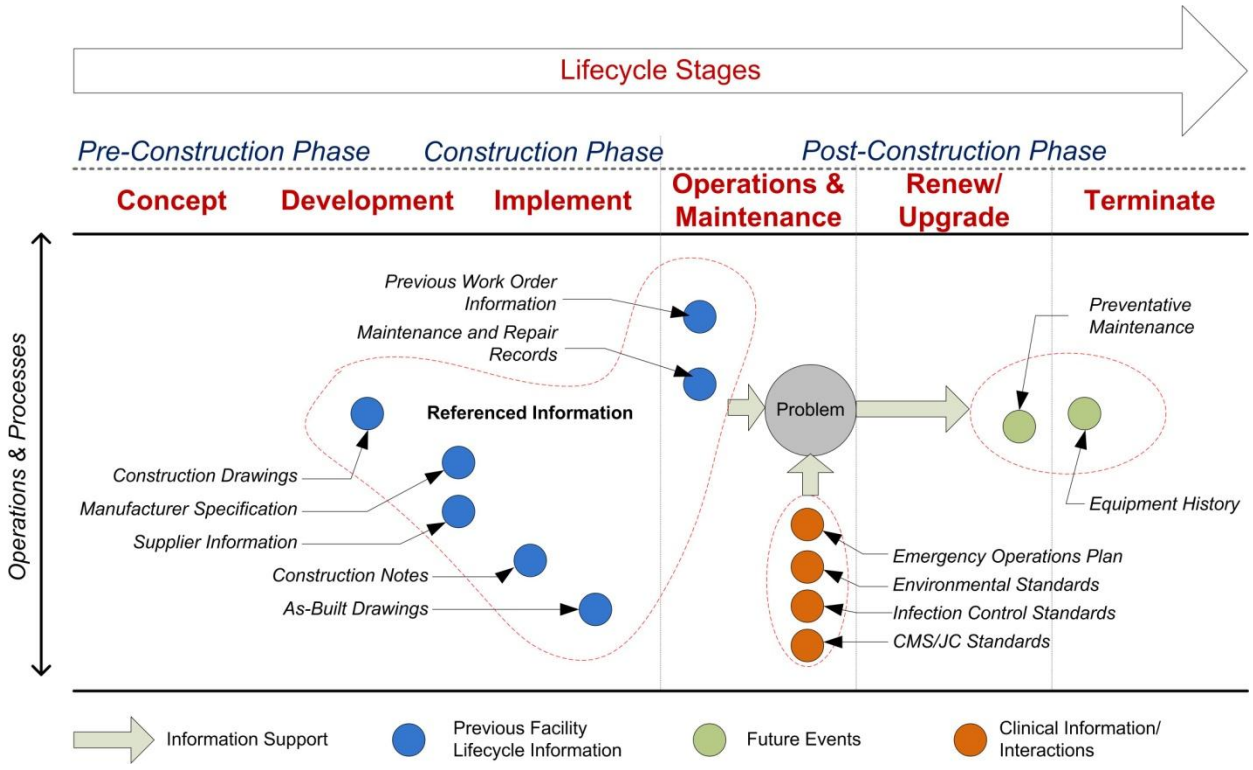

Figure 2: Horizontal (facility) and Vertical (clinical) information support of problem

If a water incursion event occurs anywhere within the area of the operating suite FM personnel and the maintenance mechanics need to respond quickly and effectively. In that process there is information from throughout the project lifecycle (horizontal communication) that needs to be referenced, represented as blue dots in Figure 2. From the pre-construction and construction phases of the facility's lifecycle drawings, specifications, supplier information, and contractor notes are all referenced information to support the response of the identified problem. From the operation and maintenance phase there are maintenance notes and previous work orders. The other dimension of information referenced during this type of situation is clinical information (vertical communication). Within the clinical realm (orange dots), emergency protocols, environmental and regulatory standards, as well as occupancy information is needed during the response. Lastly, the work completed in response to the situation should be properly documented as it may be needed for determining future maintenance work or during the response to a

similar situation. Currently, most of this information is fragmented and is not centrally stored making it difficult to provide an efficient and effective response. This fragmentation adds to the inefficient use of time during facility management activities. Storing the information so it is better organized and quickly retrievable will free up facility management personnel time and will allow for a more informed on-time response. With the current method of managing information there are preventative measures and elective work that goes undone or is delayed because of the lack of resources, personnel, and time to do it. Adding personnel is not typically an option because of the expense.

1.3. Research Goal and Objectives

The research goal is to develop and evaluate a product model and ontology within a BIM-based framework to support facility management processes within a healthcare environment (Figure 3). The framework addresses the format of structuring the information needed to perform FM processes from earlier phases as well as integrating information exchange among processes within the operation and maintenance phase to allow for a more effective and efficient completion of FM processes. The product model is used for static storage of the facility related information while the ontology defines how the information and classes interact with each other and other systems connected to the product model.

Three objectives are needed in completing the goal of this research:

Objective #1: Analyze needed FM information to support operations and maintenance activities in healthcare environments using a case based approach.

- Identify information origins from previous lifecycle phases through task analysis of developed case studies (horizontal communication) by identifying, mapping, and tracking origins (phase), sources (system), types, and formats of needed information.
- Identify information needs and interfaces originating within clinical groups during operation of the facility (vertical communication).

Objective #2: Develop a BIM-based framework for information storage, retrieval and mapping.

- Create a product model and ontology to organize the information for easy storage, retrieval, and editing in supporting facility management processes within the management and operation phase of a facility.

Competency questions were developed and used to aid in designing the product model, keeping the design within a specified scope, and then used to validate the product model to ensure it fits the intended use.

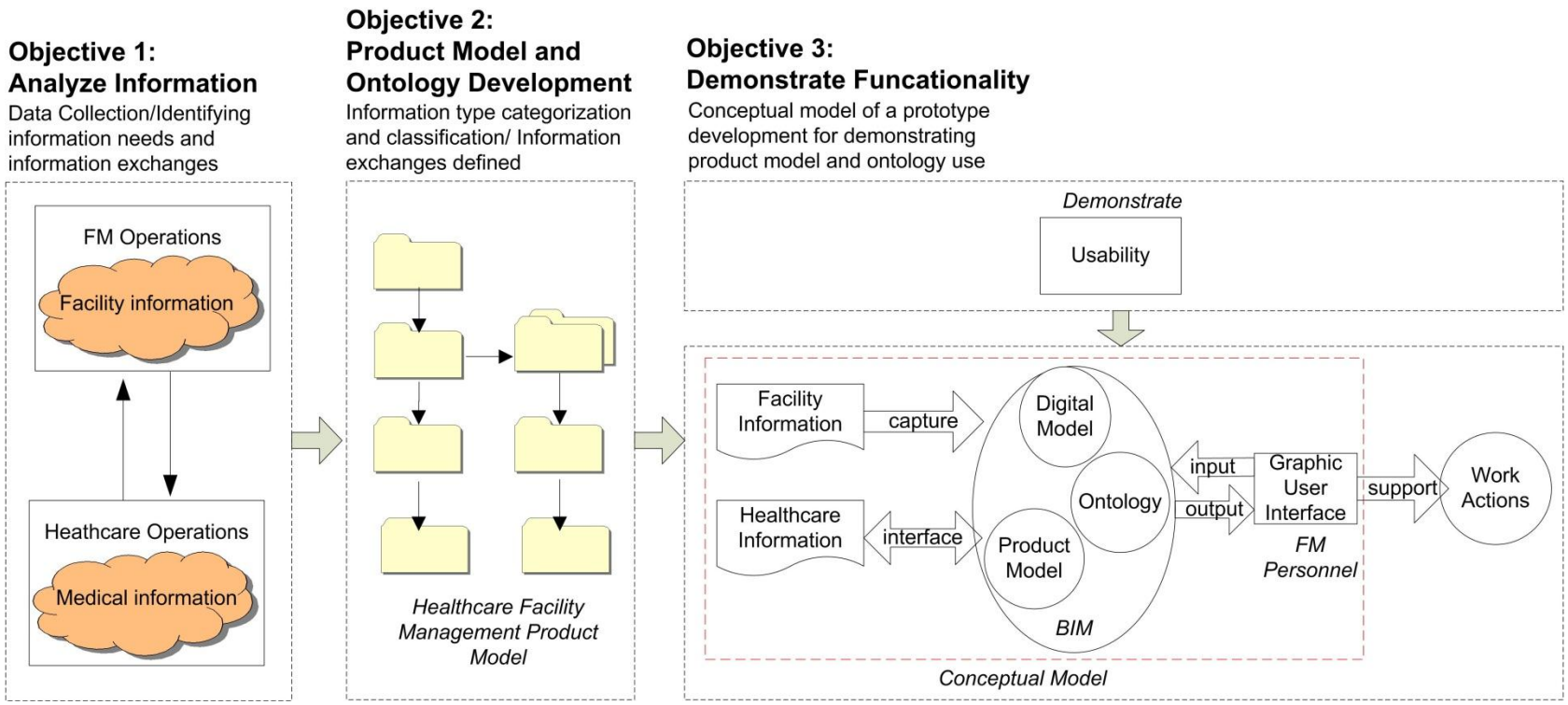

Figure 3: Objectives Overview

Objective #3: Develop a conceptual model of a prototype to demonstrate the functionality of the framework.

- Develop a system architecture mapping system functionality.
- Develop graphical user interfaces within a conceptual model to demonstrate functionality of future prototype.
- Demonstrate potential user interactions with framework.

Motivation

This research work is an expansion of an Agency for Healthcare Research and Quality (AHRQ) funded joint pilot project between Virginia Tech and Pennsylvania State University entitled "A Pilot Study for Integrating Facility Information with Healthcare Information to Improve Patient Safety" grant number 1 R03 HS19074-01. The joint project included an exploration of facility management activities and their overlap on clinical operations and patient safety in healthcare environments. As an extension of the research, the author drew upon the developed case studies to further analyze information types, origins, and formats needed to support FM activities within healthcare environments to support events dealing with mechanical systems and patient safety.

The motivation for selecting facility management and healthcare in this research includes the link described in the background between the physical environment condition and the quality of care, patient recovery outcome, and patient and staff stress. The additional cost of medical errors and patient safety events was also a determining factor for exploring methods of improving the healthcare environment. The issues of facility managers needing to do more with less also leads to the exploration of offering a more effective and efficient method to capture, store, and manage information for use during facility management activities.

Limitations and Assumptions

Three limitations were identified in completing the research. These limitations are:

Limitation #1: Framework development is focused on mechanical systems maintenance and emergency repair.

One building system and its associated problems were examined in developing the framework in order to simplify the problem set and be able to analyze the different aspects of the response process. Mechanical systems were chosen because of their importance to patient safety within healthcare environments and their complexity to maintain. The case studies were selected to show a variety of types of feasible situation involving mechanical systems and get a basic understanding of healthcare processes,

information needs, and FM activities involved in these situations. The assumption is that the framework can be easily expanded in future research to also work with other systems. By designing the product model and ontology around the processes involved in the response to a situation, the hope is that the product model can be easily expanded in the future to allow for other systems. During development more focus was given to the process than to the actual system in an attempt to make it easier to expand in the future and hopefully require fewer changes to the core of the product model.

Limitation #2: Only one healthcare organization's response to certain situations was used in developing case studies.

The case studies were developed around one healthcare organization's response to certain situations. Different organizations may have different policies and procedures in line for certain types of events. However, literature review and regulations were examined to help determine typical and proper responses. Different facilities may have different processes, however the information used to adequately resolve a situation should be the same for every facility. The case studies are used to identify the information types and formats needed to support processes which should be the same for all facilities. The typical response process is often governed by a regulation, so it should be similar enough in other facilities to be adaptable. This would need to be examined further in future research, but the types of information needed in the process and the underlying process steps were examined and incorporated into the product model and ontology to hopefully limit the need for major customization if applied to alternate healthcare facilities.

Limitation #3: Not all buildings have a developed data model with lifecycle information, existing and older facilities have mostly paper based information.

The last limitation that was noted is that not all facilities have the information available in a model format for use with this framework. The assumption for this research is that the information is available. The need to document existing buildings into a data model is a separate research agenda the needs to be undertaken. For the purposes of this research, the assumption is that a data model was used during the lifecycle of the facility and the information would be readily available.

1.4. Research Methods

This research utilized various research methods to accomplish the stated objectives. Table 1 summarizes the types of research methods used in completing each of the objectives. The use of the methodology to solve the stated problems is answered throughout the next chapters of the dissertation however the paper

Lucas (et.al., 2011a) included in Appendix A provides a summary of the problem statement and research approach.

Table 1: Research Methods Used

Method	*Objective #1*	*Objective #2*	*Objective #3*
Case Study Analysis	X		
Failure Mode Effects Analysis	X		
Fault Tree Analysis	X		
Use-cases	X		
Product Model Development		X	
Test Case Analysis		X	
Conceptual Model Development for a Prototype			X

Case Study Analysis: analysis of scenarios, or sketches of user activities that help frame an understanding of work practices and give insight into how a technology or change in workflow could augment the work (Rodriques et.al., 2001). As part of the Case Study Analysis process models, cognitive walkthroughs, and task analysis were completed. The end result of the case study analysis was the ability to identify information needs to complete each task.

Process modeling involves capturing a process in a workflow specification and are usually communication or activity based (Georgakopoulos, Harnick, and Sheth, 1995). Process models are used to document, analyze, and redesign workflows and look at information exchange and communication and methods of integrating technology to improve workflow design. The process models will be developed using Business Process Modeling Notation (BPMN) (OMG, 2011). BPMN is a graphical method of depicting the sequences of processes within a process model. A cognitive walkthrough is a type of usability inspection method that typically focuses on evaluating a design or validating a process (Wharton et.al., 1993). Task analysis is historically used to analyze work processes and optimize workflow. This has been adapted to human computer interaction and system design. Within cognitive task analysis, the goal is to gain an understanding of the domain knowledge used in completing tasks. Within physical, or manual, task analysis, work processes are examined (Crystal and Ellington, 2004). Industry meetings were performed with industry professionals who are knowledgeable of the subject. The process models were used as a basis for the FMEA, FTA, and Use-case analyses.

Failure Mode and Effects Analysis (FMEA): FMEA is used to define possible failure modes for systems and/or components. The steps in completing a FMEA are broken down to defining the system, defining the assumptions of the system, constructing functional block diagrams, identifying failure modes, performing failure effects/cause analysis, assigning detection methods and compensating provisions, and assigning severity ranking (DOA, 2006).

Fault Tree Analysis (FTA): FTA is a method for determining root causes of failures and potential failures of systems and can help the user/designer/maintainer understand how to fix or prevent the failure (Marquis, 2008). Marquis (2008) suggests six simple steps in completing FTAs as (1) select a top level event for analysis, (2) identify possible faults, (3) list causes for each fault, (4) add logical operators (and/or), (5) identify causes until a root cause can be determined, and (6) list countermeasures for root causes.

Use-cases: The Use-cases allow for documenting each individual step of the process allowing for information needs, communications between service groups and interactions with systems to be identified.

Product Model Development: Product model development methods are discussed in Chapter 2. The product model is a static representation of the information and serves as the backbone to information exchange mechanics, or the ontology. As part of the product model and ontology development, competency questions were developed and used to help define scope and validate its use. Competency questions are questions that the information supplied by the product model and ontology must be able to handle (Gruniger and Fox, 1995).

Test Case Analysis: A literature based case study was used to ensure that all information needs for the test case were included in the product model. This helped to validate the product model to ensure that it was flexible to include cases beyond the initial case studies used for development. A similar test case is used to help validate the usability of the prototype and ensure that the interfaces were not too strictly designed.

Conceptual Model Development for a Prototype: A conceptual model was developed to help validate the functionality of the framework through a prototype system. This involved developing GUIs to interact with the framework and demonstrate the potential functionality of the framework.

Figure 4 maps the research agenda by showing how each of the methods is connected to the objectives. The case study analysis is completed by creating process models and completing the FMEAs and FTAs. From these, the information can be analyzed through the development of use-cases that allow for the information needs to be mapped in support of Objective #1. Using the identified information types, a

product model and ontology is developed to organize and structure the information needed to support facility managers' response in support of Objective #2. Lastly, the GUIs and conceptual model of a prototype are developed to demonstrate the product model and ontology's use in support of Objective #3.

Objective #1: Analyze needed FM information to support operations and maintenance activities in healthcare environments.

The information analysis in Objective #1 was completed through a case study analysis. Case study analysis allows for studying and understanding of the current process (Section A of Figure 4). The basic understanding of the process is needed in order to identify the information needs and then later modify the process with the developed framework.

The case study analysis took case scenarios, developed through interviews and literature review, and analyzed them for the information needed by facility managers to complete certain tasks. The case studies were developed with the use of narratives. They were then documented in the form of process models using Business Process Model Notation (BPMN). Failure Mode and Effects Analysis (FMEA) and Fault Tree Analysis (FTA) were also completed.

The process models allow for a step by step graphical depiction of the events in each case. The BPMN process models were used to help identify needed information during each decision during the event. Since the process model shows the event as it happened, FMEAs and FTAs were used to show possible alterations and variations of the events. The FMEAs developed are developed to emphasis both facility failure factors in how operations are effected as well as health effects that would be experienced by patients. The FTAs are developed to diagnose the root cause of a problem of the faults that are identified in the FMEA. Chapter 3 section 3.1 details how each of these methods were completed. The analysis results are listed in section 3.2 and 3.3.

Case Study Validation

Cognitive walkthroughs and task analysis were conducted with industry professionals to validate the case studies and developed process models. Walkthroughs consisted of going through each step of the documented processes to ensure they were consistent with the actual (or typical) response to the situation. Any differences or variances and edits to the process model were made before the process models were used to aid in the framework development.

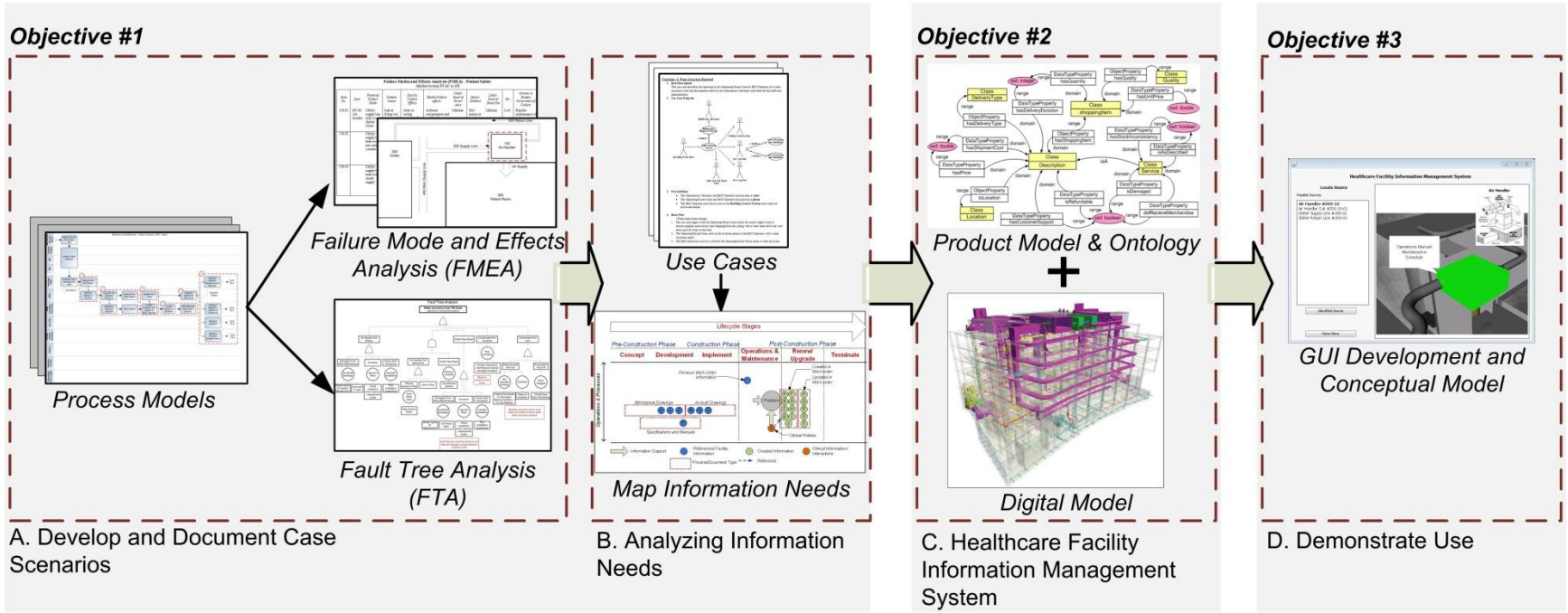

Figure 4: Research Agenda

Identifying Information Needs

Once the case studies were reviewed by industry professionals during the cognitive walkthroughs, task analysis allowed for identifying the types of tasks, cognitive and physical, that take place. This helps identify the information needed in responding to an event. The types and format (level of detail) of information needed to support each process were identified and documented. These detailed steps of the case studies were documented as UML Case Studies. The UML Case Studies were then used to help analyze the information that is needed and exchanged throughout the case study processes (Section B of Figure 4). The UML Case Studies are discussed in Chapter 3. The resulting information analysis was used to develop the product model and ontology within the BIM-based framework in Objective #2.

Objective #2: Develop a BIM-based framework for information storage, retrieval and mapping.

In Objective #2 the BIM-based framework is laid out (Section C of Figure 4). The product model and ontology used to store and manage the information serve as the backbone of the framework. The product model serves as the static representation of the knowledge based and is the basis for all information exchange mechanisms. It is represented through the use of UML Class Diagrams that consist of classes (or objects), attributes (properties of the objects), and relationships between the classes. The ontology represents the information exchange mechanisms and show how information interacts with each other as well as how the system interacts with other systems. These interactions are represented as UML Sequence Diagrams that show the behavior of classes and how they handle information. The product model is the structure for storing information while the ontology is the mechanism for capturing, retrieving, and querying the information.

The product model and ontology design process followed a structure similar to that as described by Noy and McGuinness (2001) and Gruniger and Fox (1995). The framework's design was directed to the intended use of supporting FM processes within healthcare environments. It relates systems maintenance, troubleshooting, and repair during patient safety events. The UML Use-Case analysis and information analysis completed under Objective #1 was used to determine a list of vocabulary terms which were then organized into the hierarchy of classes and class attributes. The product model was designed in a way to allow for it to be extensible and maintainable in the future. Existing product models and ontologies were examined for inclusion and connections to existing systems were also looked at. Competency questions were used to aid in both the design and preliminary evaluation of the framework. They are used to help ensure the ontology and product model contain enough information and are able to retrieve adequate information in answering specific questions based on the intended scope of the framework. An assumption of the framework's development is that the BIM model will be transferred throughout the

facility's lifecycle and linked to the framework so the identified information needs and required formats can be captured and stored for use during FM activities.

Product Model and Ontology Analysis

The product model and ontology development were validated through the use of competency questions. The competency questions were developed based on information received at industry meetings as well as through the case study analysis. To ensure that the classes and interactions that were developed did not too closely match the case studies used for design, a literature-based test case was developed. This test case was examined for information needed to complete a task or react to a situation. The information was then input into the product model and the information exchanges were examined to make sure all needed information was available through the product model. Lastly to demonstrate the usability of the product model and ontology a conceptual model for a prototype is developed under Objective #3. The product model and ontology development and analysis are discussed in detail in chapter 4.

Objective #3: ***Develop a conceptual model for a prototype to demonstrate the functionality of the framework.***

A conceptual model for a prototype was used to demonstrate the potential usability of the framework. The conceptual model shows the possible functionality of how a user can interact with the framework and serves as an outline for a future prototype development. Figure 5 shows the overall components of the prototype depicted by the conceptual model (section D of Figure 4). A Graphical User Interface (GUI) is used to interact with the framework and allow the user to retrieve information from the product model. The GUI allows the user to (1) query information based on an identified problem. The ontology (2) filters the information from the product model, (3) formats the information, and (4) outputs the information to the user. Based on the user's needs, the prototype would help the user walk through a series of steps aiding in the response and repair process.

The framework would be used by FM personnel in responding to emergency events. Relevant clinical information pertaining to codes and standards that affect the maintenance, operation, or repair of a system are included within the product model. The targeted end-user would be FM personnel and the goal is to offer an effective and efficient method of accessing needed information that currently requires searching multiple databases, plans, specifications, or having a knowledgeable person. It should reduce required response and planning time by allowing access to all needed information in one location.

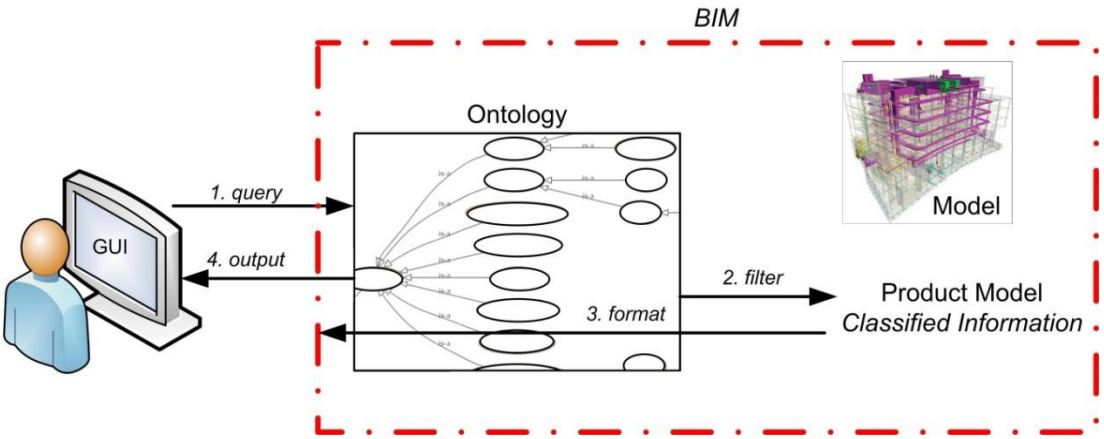

Figure 5: System Components

The conceptual model is used to demonstrate the potential use of the product model and helps to validate the usefulness of the product model and ontology as an adequate method of organizing healthcare facility information within a BIM-based environment. The conceptual model uses the developed case studies to design a series of user interfaces that support the response process. The GUIs are mapped to the product model to show information exchanges and how the user interacts with the framework in responding to emergency events. The information would be tied to the building model to allow for a spatial connection of information. This also helps the user to select proper locations and visualize components that may need to be checked or repaired during the response process.

Analysis of Prototype/Framework

The model is developed around the situations that arise in mechanical systems that are included within the case studies that were used during its design. To ensure that it is flexible for use in other situations and not only designed around the design case studies, a test case is used. The test case analysis used a separate case study. The processes needed to respond to the test case were mapped against the developed model to make sure that the design of the GUIs allowed for accessing the needed information from the framework.

Conceptual model development and analysis are discussed in detail in Chapter 5.

1.5. Contribution

The major contribution of this work is a product model and ontology framework that takes both clinical and building information related to facility management events and structures it for efficient use. The product model and ontology framework address the issued identified within the problem statement of fragmented information horizontally throughout the facility lifecycle and vertically between concurrent

processes within the operation and maintenance phase. The framework links relevant clinical information and facility information with possible event types to assist facility managers in their efficient response. This was completed by tracking and mapping the information that is needed to support facility management processes and identifying information links between facility management information and clinical information. The tracking and mapping of the information allows for the information to be captured and stored within the designed product model throughout the lifecycle of the facility to support downstream processes, specifically those pertaining to facility management activities. By identifying the links between facility information and clinical information, information exchange mechanisms were included within the design framework to ensure that appropriate clinical information is readily available when needed. The product model and ontology serve as the core information storage and exchange mechanisms for the overall proposed healthcare facility information management framework.

The contributions and benefits are discussed in detail in Chapter 6 section 6.2.

1.6. Document Organization

The *Introduction* is used to give a broad overview of the document and lays out the research problem, objectives, and methodology used in this dissertational research.

Chapter 2. *Background and Literature Review* consists of a review of current and relevant literature related to the research problem and objectives. This includes an analysis of healthcare environments and how the design of the physical environment is connected patient safety and clinical operations. An analysis of healthcare regulations and standards pertaining to the operations and maintenance of the facility is also included. Current literature pertaining to research uses of BIM and ontology within healthcare facilities and facility lifecycle management is also discussed.

Chapter 3. *Case Analysis Methods for Identifying Information Links* is a chapter that discusses the case studies that were developed and the analysis methods used to determine the information needs for supporting facility management activities within a healthcare setting in response to objective #1. Links between facility management activities and information to clinical activities and information is also discussed in this chapter.

Chapter 4: The chapter *A Healthcare Facility Information Management Framework* discusses how the findings from the case study analysis of Chapter 3 are used to organize the information into the framework in response to objective #2. The chapter discusses the information exchanges within the product model and ontology.

Chapter 5: *Conceptual Model Implementation* is a chapter that discusses the development of a conceptual model that demonstrates the potential usability and functionality of the framework. The chapter discusses the system architecture, GUI development, and test case analysis.

Chapter 6: The *Conclusion and Future Research* chapter summarizes the findings and discusses the contribution and benefits of the research. This chapter also includes discussion on possible future research tracks and how they might be accomplished.

2. BACKGROUND & LITERATURE REVIEW

The topics of literature reviewed in support of the research are healthcare environments, healthcare environment standards and guidelines, product models, ontology, and BIM and IT use in both healthcare and facility management.

In conducting this research it is important to understand philosophies and other research dealing with the physical healthcare environment. Specifically, the link of the physical environment of care to the quality of care of patients and clinical staff is examined. Specific focus has been put on examining areas that link the maintenance and quality of maintenance of the physical environment to patient care, recovery time, stress of patient and staff, and infection control.

Expanding on the subject of the physical healthcare environment is the exploration of healthcare environment standards and guidelines. The standards and guidelines that a facility manager and their staff must be familiar with were looked at. The goal of this study was to gain an understanding of what is required of FM while maintaining the healthcare facilities. The standards and regulations examined were limited to those listed by the American Society of Healthcare Engineers (www.ashe.org) with the addition of what is listed for healthcare facilities in the International Building Code (IBC).

The topics of product models and ontology are also reviewed. This review is completed to gain an understanding of methods used in creating a product model and ontology, development languages and tools, and to gain an understanding of each relate to BIM, facility lifecycle management, and healthcare management.

Lastly, the use of BIM in FM and healthcare is reviewed. This is to gain an understanding of the current uses of BIM in FM. Separately, the use of BIM within healthcare is examined to help gain an understanding of how BIM is specifically used within the healthcare sector of the AEC/FM industry.

2.1. Definitions

Definitions of relevant terms as each pertains to this research are as follows:

Healthcare Environment: is the physical environment of care or the environment which care is given, this includes the actual building or facility and all relevant systems (e.g. heating, mechanical gas, etc.).

Product Model: is an object-oriented model representing domain information of a product, in the arena of the built environment, the product is a building. A product model not only stores the information but is used in the implementation of data exchange mechanism (Eastman, 1999).

Ontology: an ontology is defined as a set of definitions for information behavior and use within the system (Gruber, 1993). An ontology is related to a product model as it is defining the data exchange mechanisms. Two types of ontologies are looked at, those that deal with Facility Management and those that deal with Healthcare.

BIM (Building Information Model): BIM is an object-oriented, information rich, intelligent model to support the decision making processes through the facility's lifecycle (Eastman et.al., 2008). BIM in the context of the research is not simply a 3D model or one piece of software, but an information repository to be accessed to FM operations.

Facility Management (FM): the operation and maintenance phase of a facility's lifecycle dealing with processes such as repair, scheduling, coordination of renovation, and building systems operations.

2.2. Healthcare Environments

Healthcare environments are the environments in which patients recover or receive care. There is noted importance amongst research of the quality of the physical environment and its link to patient and staff well-being and safety. A healthy building with quality lighting and air quality has been linked to better productivity by its occupants (Clements-Croom, 2003). Similar features have also been noted within healthcare environments as having an effect on patient well-being and safety. Several reviews of multiple trials and studies have been compiled listing the benefits of a quality physical environment for healthcare. Those studies are listed below with a summary of the compiled benefits. Since the research is dealing with FM in healthcare environment articles that deal with design features and new building design were not included.

Within healthcare environments it is important to create a healing environment for the patient while balancing the needs of healthcare staff to make administering care easier (Stichler, 2004). Ambient environmental stimuli, such as air quality, odor, and lighting, as well as aesthetic interior design features help improve patient outcome by reducing length of stays and leaving patients with a healthier prognosis and quicker recovery (Dijkstra, Pieterse, and Pruyn 2006). Though the cost to implement certain features can become a deterrent in resource strapped healthcare facilities, design and environmental stimuli features that have shown success and benefits to the healthcare delivery system and patient safety have led to evidence based design criteria in new or remodeled facilities to help improve the healthcare delivery system (Shoemaker, Kazley, and White, 2010). An environment that is designed and maintained to minimize stress on both the patient and healthcare worker by including features of better air quality, noise control, thermal comfort, and quality lighting among other features has a positive effect by

reducing staff stress and fatigue, increasing effectiveness in delivering care, improving patient safety, reducing stress, improving outcome of care, and improving overall healthcare quality (Ulrich et. al, 2004).

Connected to the design is the maintenance of the features, spaces, and systems to ensure patient comfort and safety. The ambient environment stimuli of good air quality, lack of unpleasant odor, and quality lighting were among the top reasons for patient satisfaction with the physical environment of care, which also correlated to overall satisfaction with healthcare services during a hospital stay (Harris et.al., 2002; Devlin and Arneill, 2003).

The design of the facility is important for the overall care and operation, however in terms of facility management, the structure and other physical features may not be easily modified. Patient-centered care, where the patient has some control over care and comfort, is a trend within the healthcare industry. Devlin and Arneill (2003) summarized studies linked to patient control. The perceptions of control over acoustics/noise, lighting, temperature, and privacy were listed as contributing factors of how patients perceive their environment. Control over these issues can lower patient stress, thus improving outcome and recovery.

Not only do air quality, odor, and light have an effect on patient outcome from reducing stress and increasing satisfaction, it also affects patient safety by reducing possibilities for infection. It is important to ensure maintained systems for the health of all building occupants. Airborne and waterborne contaminants and other environmental disturbances (such as those caused by construction and renovation) can cause spread of infection and illness, especially within a healthcare setting where the occupants of the structure have depleted immune systems. Proper cleaning and maintenance of systems is required to reduce the risk to patients and improve overall quality of the environment (Sehulster and Chinn, 2003), it is important for facility management personnel to be aware of different procedures and policies to reduce the risk of spreading infection.

Patient safety and reduction of nursing errors and increase in efficiency of care are also linked to the design of the environment of care. Inadequacy in the physical environment can contribute to staff fatigue, stress, and burnout and result in additional errors. A review of related studies concluded that noise levels, ergonomics/furniture/equipment, lighting, and design/layout are features of the physical environment that effect staff burnout (Chaudhury, Mahmood, and Valent, 2009).

Summary of Healthcare Environments

The referenced studies show links between the quality of the physical environment and the quality of patient care. Since the research is dealing with FM within healthcare environments, facility managers do

not often have control over the existing layout of spaces. They do, however, have control over important maintenance issues listed within the studies. These include issues of air quality, proper cleaning, comfort, and light quality.

Maintenance of healthcare facilities often run behind the scenes and maintenance activities are often confined to taking place when most convenient for clinical operations. However, in times of emergency it is important for facility managers to have adequate information and the correct contacts within clinical personnel to make the quick decisions to minimize damage and disturbance to clinical operations. Facility managers are tasked with keeping order of a number of dynamic systems within healthcare environments that are constantly changing with renovations and new construction, staff and patients constantly moving through the buildings, and services needing specific utilities and environmental conditions. It is important for effective and efficient FM operations within healthcare environments to maintain a required standard of care. There is a constant demand to do more with less, facility managers are under resourced, this requires an examination of the current processes to see where they can be improved and made more efficient to maintain the quality of care. This demand coupled with the importance of a well maintained physical environment within a healthcare setting is a motivating factor for conducting this research.

2.3. Healthcare Facilities Guidelines and Standards Analysis

The role of facility managers is to ensure that the environment they work in is adequately maintained and operational. This offers comfort and safety to the facility's occupants. In healthcare facilities, Facility Management (FM) operations become critical to the safety and health of patients and clinical staff. FM personnel must operate and maintain complex systems with minimum interruption to the functions of the hospital. The state of healthcare environments, or the physical space in which patients recover or receive care, are important for the health, well-being, and quality of care patients receive within a healthcare facility (Ulrich et.al., 2004). Well maintained, clean, and quiet rooms are closely linked to patient satisfaction with the healthcare delivery process (Devlin and Arneill, 2003; Harris et.al., 2002).

To maintain the healthcare environment, FM needs to manage a range of input from facility and system information to standards and guidelines. Facility and system information comes from design, construction, and maintenance activities earlier in the facility's lifecycle. This information is often fragmented, coming from multiple sources and can be difficult to manage and track. On top of the facility and system information typical to any facility, hospital facility managers are required to be familiar with various standards and guidelines that cover different areas of managing a healthcare facility. These standards and regulations help to promote healthy environments and quality of care. The topics they cover

range from design information and maintenance information to administrative and procedural type information. *Continuous compliance*, or *continued readiness*, is a proactive method for maintaining an understanding of what is required (Stymiest, 2011). In order to be continually ready for surveys, it is important for facility managers to have an understanding of each code and guideline and know what they are expected to conform to while managing a healthcare facility.

This section surveys the existing standards used for design, construction, and operation of a healthcare facility. Each code is analyzed for its scope relevant to facility management's role within the healthcare environment. The codes are also examined for overlaps and gaps in how the design and construction codes support the operation of the facility. Lastly, how the codes and regulations can be incorporated into a healthcare facility information management framework is discussed with examples of how different standards guide facility operations.

Methods

The code analysis is completed by examining each code individually to determine their coverage areas and to determine which way the code is written and who it is directed to. A comparative matrix is also completed. This allows the coverage areas of each code to be compared and see where specific topics of each code may overlap with other codes. A gap analysis was performed by looking at the codes directed towards design and construction to understand how they support the needs required by the codes directed for operation and performance of the facility. With an understanding of how the codes influence certain facility operations, consideration is taken to which codes can be directly incorporated into the facility information framework to aid facility managers in performing tasks. Possible examples are discussed in the context of a case example.

Compliance logistics

In order to provide *Continuous Compliance*, the FM personnel have to be familiar with codes and regulations that are related to the operation and performance of the facility. These regulations come from a variety of sources. The *American Society for Healthcare Engineering* (ASHE) of the *American Hospital Association* (ASHE, 2011a) lists a total of nine sources for codes, standards, and regulations that apply to the operation and maintenance of a healthcare facility. The completed analysis included the codes listed by ASHE with the addition of the International Building Code (IBC). The IBC code was added to the suggested list by ASHE because of the degree of renovation and addition that facility managers within healthcare are responsible for planning. Maintaining continuous compliance is complicated by constantly changing hospital technologies. These changing technologies often required

renovation and additions to the facility, which facility managers are required to coordinate while maintaining clinical operations.

Healthcare standards for facility managers

The analyzed codes and standards are from nine different groups listed by the ASHE as important to FM practices in healthcare. These groups and corresponding codes are listed below.

1. *The Joint Commission* (JC) provides the voluntary accreditation program for hospitals and other healthcare services. The JC offers The Environment of Care (Miller, 2004), a standard that defines the requirements of environmental management programs for facility and clinical operations staff.
2. *The National Fire Protection Association (NFPA)* establishes codes, standards, guidelines, and recommended practices for the prevention and control of fire. The NFPA 101 – Life Safety Code (Cote, 2009) covers a variety of fire and life safety related topics, some specific to healthcare environments and hospitals.
3. *The Centers for Disease Control and Prevention (CDC)* is the leading federal agency for protection of health and safety of people. The CDC releases Guidelines for Environmental Infection Control in Health Care Facilities (Sehulster and Chinn, 2003) that give a comprehensive approach to environmental infection control in healthcare environments.
4. *The Centers for Medicare and Medicaid Services (CMS)* – is a federal agency that administers quality standards in healthcare. For a healthcare organization to be certified to receive Medicare and Medicaid program payment, it must comply with the Conditions of Participation (MacDonald, 2004), which are standards set forth in federal regulations.
5. *The Occupational Safety and Health Administration (OSHA)* is a federal agency which aims to prevent work-related injuries, illness, and deaths (OSHA, 2011). They have developed computerized graphical eTools to help employers identify and address potential occupational hazards in hospitals.
6. *Environmental Protection Agency (EPA)* imposes standards to protect the environment. EPA programs of interest to healthcare organizations are the Air Emissions permitting (Clean Air Act) (EPA, 2011a), Waste Water Permitting (Clean Water Act) (EPA, 2011b), Medical Waste Incineration (EPA, 2011c), and Underground Storage Tanks (EPA, 2011d).
7. *The Food and Drug Administration (FDA)* supervises the development, testing, storage, and monitoring of food and drug products as well as medical equipment (FDA, 2011).
8. *The American Institute of Architects (AIA)* is a professional organization for architects in the United States and publishes the Guidelines for Design and Construction of Health Care Facilities

(Facility Guidelines Institute, 2006) which is commonly referred to as the AIA Guidelines within healthcare.

9. *The United States Pharmacopeia (USP)* sets standards for all prescription and over-the-counter medicines, dietary supplements, and other healthcare products manufactured and sold in the United States. The USP 797 (U.S. Pharmacopeia, 2008) is a standard that provides guidance on achieving and maintaining sterility from contamination of compounded pharmaceutical products, included within this standard is regulations for the physical environment and environmental quality of pharmaceutical compounding and storage rooms.

In addition to the standards and guidelines advised by the ASHE, the International Code Counsel's (ICC) International Building Code (IBC) was also examined (ICC, 2009). The IBC is the code that governs design and construction regulations for any type of facility. IBC has specific code provisions concerning the I-2 Occupancy group which is the classification of hospitals and other healthcare centers. It is critical to add the IBC to the codes listed by ASHE because it covers concerns with renovation processes and design of the use group.

The IBC, NFPA 101 Life Safety Code, and the AIA Documents were all written with the intent of covering design and construction standards. The other standards included in the comparison are more directly related to the operation and performance of the facility. Even though the IBC, NFPA, and AIA documents are more directed for design and construction, it is still important for facility managers to have a complete understanding of these requirements during renovations, repairs, and additions to the facility. There are areas of these codes, specifically within the NFPA, that need to be maintained throughout the operation of the facility, such as keeping a clear path of egress in case of fire or evacuation emergency. These types of codes are relevant to all personnel to ensure they are consistently compliant and are not storing medical carts, equipment, or supplies in a manner that would compromise the safety of the facility.

The JC/Environment of Care covers areas of administration by ensuring certain programs are put in place. Environment of Care requirements are written as performance based codes. They include items such as "a safety program must exist" with a prescriptive requirement of what should be included but little exact conformance detail. It is the responsibility of various facility personnel to ensure that the Environment of Care is met. Within the Environment of Care, other codes are referenced that are more specific to a single area of the healthcare environment, such as cleaning according to the CDC guidelines or maintaining a safe work place in reference to OSHA guidelines. These other codes pertain to certain aspects of managing and maintaining healthcare environments.

The CDC provides guidelines for helping to control the spread of infection. The most relevant areas of this code for FM are the clauses that include aspects of cleaning, maintaining air and water systems, water incursion abatement, and renovation procedures. There is discussion within CDC guidelines about proper chemicals, cleaning solutions, rags, and supplies to use during cleaning. There is also information pertaining to proper air flows, filtration, and testing methods to maintain air systems. Information pertaining to water systems includes the proper procedures to make sure that water borne microbes found in stagnant water are cleansed from the system. As for water incursion abatement there are strict moisture testing guidelines as well as timelines for properly drying, cleaning, or repairing affected surfaces.

The CMS covers areas of management that are required for healthcare facilities. They are performance guidelines to ensure the quality of care given to the patients with some limited procedural information. The areas of the CMS document that are important for FM are similar in nature to the information included within the Environment of Care documents that deals directly with patient safety within the environment.

OSHA focuses on workplace safety to help prepare for issues within a healthcare environment pertaining to radiation exposure, chemical exposure, and biohazard material exposure. General OSHA regulations as part of the Code of Federal Regulations that are for all occupations are also relevant to work being conducted during regular maintenance in healthcare such as the use of ladders and other equipment or maintaining electrical and mechanical systems.

The FDA affects the management of facilities by licensing products and equipment that are considered safe for healthcare environments and patient treatment. FM is required to maintain and sometimes procure equipment and products and need to make sure they fit within the FDA's requirements. There are also regulations within the FDA for proper food storage and medical refrigeration systems. These systems are commonly maintained by FM.

The EPA documents concerning healthcare and facility management are mostly concerned with the quality of environment and ensure that waste and waste water are properly disposed of and controlled. The EPA also has guidelines for disposing of medical waste which is typically controlled within the healthcare environment by environmental health services, a division commonly found under facility management office.

The USP 797 deals mostly with the creation and handling of medication. The areas of the regulation that are relevant to FM relate to the mechanical and refrigeration systems that are used in the compounding and storage of medications in hospitals. There are specific air quality and air filtration requirements for

sterile environments. There are also specific temperatures and humidity at which medications need to be compounded and stored. FM is responsible for making sure that the environment fits within the requirements listed under the USP 797.

Analysis and Comparison

A direct one-to-one comparison of all the included regulations and standards is difficult since the codes were written with different intentions and cover different aspects of managing the healthcare environment and facility performance. Some codes and standards do have overlaps in areas of the healthcare operations that they cover. Those overlaps are noted and examined for consistencies. The analysis is undertaken at two levels. The first level of analysis looks at the types of codes and relevant topic areas that are covered. Only topics directly related with the maintenance, operation, and performance of the physical environment are included within the comparison matrix. General topic areas of "Safety and Safety Management", "Security", "Hazardous Materials and Waste", "Emergency Management", "Fire Safety", "Medical Equipment", "Utilities", "Housekeeping", "Design", "Construction/Renovation", "Medication Safety", "Food Safety", and "Infection Control" were used in creating the comparison matrix. Table 2 shows a portion of the completed matrix for the topic "Hazardous Materials and Waste". Category topics were chosen based on common topic themes among the regulations and standards. For instance, under the Environment of Care there is a section titled "Utilities Management" and under the CDC Documents sections are titled "Ventilation Specifications for Health-Care Facilities" and "Procedure for Cleaning Cooling Towers and Related Equipment". All of these codes deal with the operation and maintenance of different utility systems within the healthcare environment so within the analysis they were all included under an umbrella title of "Utilities". The other titles within the analysis table were created in similar ways. The analysis was limited to these topics based on their relationship to the operation and performance of the physical environment. The relationship of the topic areas to the physical environment are summarized in Table 3.

Table 2: Portion of Regulation Comparison Matrix (Complete Matrix in Appendix B)

	Standard/Regulation by Organization									
Category/Topic	*JC/Environment of Care*	*NFPA - Life Safety Code*	*CDC - Guidelines for Environmental Infection Control*	*Centers for Medicare and Medicaid Services*	*OSHA*	*EPA*	*Food and Drug Administration (FDA)*	*AIA - Design and Construction of Healthcare Facilities*	*United States Pharmacopeia – USP 797*	*IBC*
Hazardous Materials and Waste	1			2	1			2		
- Sharps containers	X									
- Hazardous material management and handling					X					
- Radiation sources checking				X				X		
- Radiation worker screening				X				X		

Table 3: Topic Link to Physical Environment

Topic	*Relationship to Physical Environment*
Safety and Safety/Management	• Safety of patients and occupants of the building through maintenance of facility
Security	• Patient, employee, and visitor safety/security. • Operation of doors, latches, locks and security of supplies, patient records, etc.
Hazardous Materials/Waste	• Proper storage and disposal of medical waste. • Proper storage of medical supplies. • Maintenance of gas systems
Emergency Management	• Emergency and back-up systems maintenance • Contingency measures for when infrastructure systems fail
Fire Safety	• Fire Control and Alert Systems testing and maintenance
Medical Equipment	• Proper electrical supplies for medical equipment • Preventative and regular maintenance of equipment and fixed systems
Utilities	• Air and water quality control • Emissions control • Temperature and ventilation
Housekeeping	• Cleaning and disinfecting standards
Design	• Programming requirements (e.g. Nursing station location) • Wall assembly requirements • Accessibility guidelines
Construction/Renovation	• Containment methods • Air quality testing requirements
Medication Safety	• Air quality, temperature, humidity of storage rooms • Compounding room requirements
Food Safety	• Refrigeration systems for food • Cook and storage systems
Infection Control	• Positive and negative room pressures • Disease transmission safety with water and air quality

The top level analysis produced thirteen distinct topic areas covered by the recommended codes. These topics are shown in Table 4. The second level of analysis was done through each topic area to see what sub-topics were covered by each standard or regulation. Within each of the main topic areas, sub-topics were created based on the code/guideline individual clauses or recommendations. The topics and sub-topic areas of each reviewed code were input into the comparison matrix in order to complete a qualitative analysis. The rows of the matrix show the topic and related sub-topics while the columns relate the sub-topics to a particular code/guideline (Table 2). Table 4 shows a summary of the areas that each document covers. The numbers within each column show the number of sub-topics under each group within each regulation.

Table 4: Document Coverage Areas

			Topic Area												
			Safety & Safety Management	Security	Hazardous Materials/Waste	Emergency Management	Fire Safety	Medical Equipment	Utilities	Housekeeping	Design	Construction/Renovation	Medication Sasfety	Food Safety	Infection Control
		(No. of Sub-topics)	14	3	4	5	7	8	12	5	27	4	13	6	7
Standard/Guideline	**Operations and Performance**	JC/Environment of Care	6	3	1	3		4	3	3			5	3	
		USP 797						1		1	1		7		
		CDC				2			3	1		2			5
		CMS	3		2				1		1		1	3	2
		OSHA	3		1		1						1		
		EPA	1						5						
		FDA	1					1					1	1	
	Design/ Construction	AIA Document			2	2	6	2	4	2	10	1	7		4
		NFPA - Life Safety Code					5				6				
		IBC					5		1		23	2			

As seen in Table 4, there are three documents that cover performance topics in a wide variety of areas for the hospital or healthcare facility: the JC/Environment of Care, the AIA Document, and the IBC. The other guidelines are more focused on their relative subjects dealing with the operation of the facility. Table 5 shows a listing of each topic area and the amount of coverage each subtopic has by two or more of the reviewed codes.

Table 5: Subtopic Coverage

Topic	# of Subtopics	# of Overlaps	% of Overlaps
Safety and Safety Management	14	0	0%
Security	3	0	0%
Hazardous Materials and Waste	4	2	50%
Emergency Management	5	2	40%
Fire Safety	7	6	85%
Medical Equipment	8	0	0%
Utilities	12	4	25%
Housekeeping	5	2	40%
Design	27	11	41%
Construction/Renovation	4	1	25%
Medication Safety	13	7	54%
Food Safety	6	1	17%
Infection Control	7	4	58%
Total Sub-Topics	*115*	*40*	*34%*

Table 4 shows a stronger correlation with the summary of topics especially for Safety Management and Utilities, but the codes cover different areas of these topics and as seen in Table 5 there is 0% overlap. For instance within "Safety and Safety Management", the FDA is interested in Medical Device Safety, OSHA is interested in protection against pathogens, burns, and trips, slips, and falls, while the EPA is interested in medical use of mercury and CMS is concerned with patient safety, quality of care, and medical service standards as they pertain to patient safety and care.

The direct one-to-one comparison is difficult across the entire group of regulations since, as shown in Table 5, only 34% of the subtopics are covered by more than one referenced guideline or standard. Some of the sub-topics that have overlap between the different phases of the project (design/construction vs. operation/performance) are included in the gap analysis later in the paper. The other sections with overlap of 40% or more are considered a significant overlap and discussed below.

Hazardous Materials and Waste has an overlap and similar requirement in both the CMS and AIA Design documents for "radiation source checking" and "radiation worker screening" causing a 50% overlap. Under Emergency Management, the JC and AIA Documents discuss "emergency equipment" and the CDC and AIA Documents discuss "Remediation for airborne contaminate emergencies" causing a 40% overlap. In both cases the requirements are in support and do not contradict each other.

Other codes, such as the AIA Documents, IBC, and NFPA – Life Safety Code have more overlap and deal mostly with design related features of the facility or fire safety. These are not completely one-to-one correlations, but a synthesized group of codes that are related. "Fire Safety" has an 85% overlap in sub-

topic coverage between the AIA Document, IBC, and NFPA – Life Safety Code with some fire protection being discussed within the OSHA documents, dealing with the safe working area for employees. "Design" has a 41% coverage overlap, between these three codes. All the sub-topics are from either the AIA Document, IBC, or NFPA – Life Safety code except for pharmaceutical compounding room design requirements, found within the "USP 797", and a relatively vague requirements of CMS that the "design must promote safety".

The IBC and NFPA codes are the closest linked for comparison. ASHE has completed a code summary report of design and construction code requirements for new buildings and has released the comparison in a table (ASHE, 2011b). The codes they compared are the NFPA 101 Life Safety Codes between 2000, 2009, and the proposed 2012 addition, and those of the 2009 IBC. These are codes that facility managers of healthcare facilities are interested in. The IBC is the design standard accepted by the state (and federal) governments for design and construction with the addition of the 2009 (and once its approved 2012) edition of the NFPA 101. However, currently, the JC and CMS require compliance with the 2000 edition of the NFPA 101.

According to the ASHE report, out of the 228 total component/requirements listed in the table, 79 requirements match identically between codes and an additional 15 have different language but can be interpreted in the same way. The remaining 134 have varying degrees of differences. 34 component/requirements are covered within the IBC but not covered at all in the NFPA. Conversely, the NFPA 101 covers 30 component/requirements that are not covered in the IBC. The IBC has 14 similar component/requirements that are more detailed than the equivalent requirement within the NFPA 101. 13 Component/Requirements are more detailed in a version of NFPA 101 than in the IBC. 14 Component/Requirements have been updated between the 2000 and 2009 or 2012 version of the NFPA 101 requiring familiarity with the most recent version of the code for construction but compliance with 2000 to meet JC/CMS requirements. The 2009 and 2012 updates can be viewed as exceeding the 2000 requirements in the cases where the component/requirements were updated or added. No components/requirements were removed that would make the facility non-compliant by following the 2009/2012 versions of the NFPA 101.

Most of the topics discussed in the IBC are for any type of facility with some variations depending on occupancy. Specific I-2 classification design requirements for hospitals and healthcare facilities exist. These include specific requirements for fire separation, corridor design, and areas that can be joined to a corridor, such as a nursing station. As an addition to IBC requirements, the NFPA 101 – Life Safety

Code gives additional detailed information on issues concerning fire safety, proper egress design, and other safety related issues. It is a reference standard commonly referred to within the IBC.

The AIA Documents overlap with the IBC and NFPA under the categories of "Fire Safety", with 6 related subtopics, and of "Design", with 10 related subtopics. When this is the case, the AIA documents are more specific in terms in details than the IBC and NFPA 101 codes, but do not contradict these codes.

"Housekeeping" requirements have an overlap of 2 sub-topics. The AIA Documents discuss the need to design corridors and spaces in a way that the carts can be parked and not block the corridor. This supports the JC's requirement that carts cannot block the passage through a corridor. There is a similar support of regulations under "Medication Safety" where 5 of the overlaps are between the JC and the AIA Documents and USP. JC discusses the enforcement of the AIA and USP requirements for environment design and quality.

The last topic area with significant overlap of 58% is "Infection Control". The CDC and AIA Documents overlap with discussion of "Airborne sources and containment specifications" and having required "steps for epidemiological investigations" as they related to facility events. The CMS and AIA overlap in two other areas with having requirements for personnel to track and record cases to identify trends and requiring that an active plan is in place to control infections.

Gap Analysis between standards and regulations

The codes referenced cover two phases of the facility's lifecycle, the design/construction phase and then maintenance/operations phase of the facility. A gap analysis was then performed between codes aimed at *design/construction* and those that deal with *operations and maintenance of healthcare facilities*. The IBC, NFPA 101, and AIA Documents were examined to identify any gaps in their ability to support the operations of the facility in accordance with the JC/Environment of Care, CDC, CMS, OSHA, EPA, FDA, or USP 797 codes and guidelines. **Gap analysis** originates out of business project management with examining where a business is, as compared to where they want to be, and identifying what gaps they need to overcome to get there (Grundy and Brown, 2002). Gap analysis can be applied in other industries by identifying areas that need to be filled to make better accomplish a goal. Gaps are typically viewed as opportunities for improvement. In this research, the analyzed gaps are voids between the design/construction and operation/performance standards and regulations pertinent to FM.

Table 6 summarizes the comparison matrix from Table 2 in terms of sub-topics within the topic areas that are covered by both Design/Construction standards and the regulations dealing with operation and performance of the facility. As the table shows there are several categories that deal strictly with the

operation and performance of the facility such as "Safety and Safety Management" and "Security". There are other topics that deal heavily with design and construction such as the "Design" and "Fire Safety" topics which have minimal concern with the operation of the facility. Other topics have sub-topics that are concerning both the design/construction and operation and performance but have no overlaps, such as "Medical Equipment" which speaks of the location and allowances for storage and clearances within the AIA documents but the operations standards include sub-topics of maintenance and cleaning. The topic categories that have overlaps are the basis for the gap analysis.

Table 6: Summary Design/Construction vs. Operation/Performance Sub-Topic Overlap

Topic	**Total Subtopics**	**Design/Construction Subtopics**	**Operation and Performance Subtopics**	**# of Subtopic Overlaps**	**% of Subtopic Overlaps**
Safety and Safety Management	14	0	14	0	0%
Security	3	0	3	0	0%
Hazard Management	4	2	4	2	50%
Emergency Management	5	2	5	2	40%
Fire Safety	7	7	1	1	14%
Medical Equipment	8	2	6	0	0%
Utilities	12	5	11	4	33%
Housekeeping	5	2	5	2	40%
Design	27	25	2	0	0%
Construction/Renovation	4	3	2	1	25%
Medication Safety	13	7	11	5	38%
Food Safety	6	0	6	0	0%
Infection Control	7	4	7	4	57%

The gap analysis was completed by looking at the topics and sub-topics covered by each code grouping and examining where there are areas within the designer codes that do not properly or sufficiently support the facility managers codes. Table 7 is a summary comparison table that includes the sub-topics examined within the gap analysis and the different codes that cover each sub-topic. The sub-topics are the relevant sub-topics from the comparison matrix shown in Table 2. Sub-topics specific to operation and performance that do not have a related design component were not included in this gap analysis table.

Table 7: Gap Analysis Comparison

	Design/Construction			Operation and Performance						
Requirement (Sub-topic)	*IBC*	*AIA Document*	*NFPA - Life Safety Code*	*JC/Environment of Care*	*CDC*	*CMS*	*OSHA*	*EPA*	*FDA*	*USP 797*
Air Quality		•			•			•		
Isolation Requirements		•			•					
Water Systems		•			•			•		
Electrical Requirements				•						
House Keeping		•		•	•					
Medical Storage		•		•	•				•	•
Pharmaceutical Rooms										•
Safety (design for)	•	•	•			•				
Hazardous Material Storage/Waste	•						•			
Emergency Preparedness	•	•	•	•						
Fire Safety	•	•	•	•						
Medical Waste		•						•		
Temperature/Humidity Control	•				•					
Renovation (Infection Control Safeguards)	•				•					
Renovation (Air Sampling/Air Quality)		•			•					
Infection Control (Limit spread)		•				•				

The identified gaps were then examined in terms of if and how they can be overcome with information technologies and practices within the industry. Interviews with industry personnel at a participating healthcare facility were also used as a source of data for comparison of technological solutions' and current practices' ability to support guidelines and standards. The interviews were semi-structured meetings with 10 clinical personnel including directors of infection control, patient safety, emergency medicine, nursing, and representatives from patient safety and bed access. There were also 6 facility management personnel who participated in the meetings including the director and assistant director of facilities, clinical engineering, and building operation center personnel. They are all employees of a 500 licensed bed multi-building medical campus with nearly 27,000 hospital admissions annually.

In general, the operation and performance areas that require specific designs, such as air quality, water systems, fire safety, and the other sub-topics listed are covered adequately within design/construction

standards/guidelines to fulfill the requirements during the operation of the facility. The area where there seems to be a gap is in "Electrical Requirements". The AIA and IBC do not have anything special when it comes to electrical supply for medical equipment. Though only basic electrical information is discussed in the IBC, and it does not fulfill the operational need. It was noted in meetings with industry professionals that power supply is an issue throughout the facility. There are not enough plugs and electrical supply to support the amount of equipment that is needed to provide care. This is mostly due to the age of the facility and the availability of new technology and electrical requirements for newer equipment. Operation standards and requirements ban the use of extension cords and power strips unless if they fit under strict specifications to meet a "hospital grade" requirement, even then they are not promoted because of the trip hazard associated with long cords. With the amount of equipment and technology that requires a plug in a certain area around the bed of a patient, the standard electrical requirements fall short. This gap is overcome with better communication and understanding of the expectations for what will occur within the designed space. The electrical supply issue is also complicated by the addition of new technologies into healthcare to support patient care and can easily overload a designed system that was previously adequate for the electrical requirements. The only solution to cover this gap is periodic renovation to increase the electrical supply to needed areas of the facility.

"Housekeeping" deals with two areas, cart storage and cleaning/disinfecting. Within the design standards/guidelines, the AIA documents discuss the need for proper cart storage areas, in locked rooms. Separately, the AIA documents also discuss the use of materials that can be easily cleaned and do not promote the growth of pathogens. On the operation and performance side, the JC – Environment of Care discusses proper storage, away from paths of travel and in a secured location. Also, both the JC – Environment of Care and the CDC recommendations discuss the use of specific types of cleaning agents and chemical solutions to clean surfaces to reduce the possibility of pathogen growth. In this way, the design documents from the AIA set up the design of the physical environment so it can be properly maintained in the area of housekeeping.

For "Emergency Preparedness" the three design codes discuss the need for exits and egress as well as the incorporation of back-up systems within the healthcare facility. The JC – Environment of Care on the operations and performance side requires an emergency management plan which includes evacuations and movement of occupants during an emergency. They also require the testing and use of emergency systems within these plans. The design codes for these systems adequately support the operations.

Related to the "Emergency Preparedness" is the "Fire Safety". The IBC, AIA Documents, and NFPA – Life Safety Code all discuss requirements for fire safety. These include the design and inclusion of sprinkler systems, design standards, and other alarms and safety features. The JC – Environment of Care requires the testing of the fire systems as well as the preparedness of fire evacuation plans and training as part of their safety and emergency management requirements.

Another area that may not seem like a direct correlation is during renovation with infection control and maintaining air quality. The IBC discusses the need for containment during construction and renovation activities. This includes securing the area where work is being performed so no materials or debris contaminate surrounding clinical areas in operation. On the operation and performance side, the CDC discusses the need to perform an infection control assessment. If the assessment is conducted, then it can ensure that the needed safeguards discussed in the IBC are performed. Similarly, maintaining proper air quality is important during times of renovation. The AIA Documents discuss the limitation of producing dust during renovation and methods of containing possible contaminants. Along the same line, the CDC requires air sampling to make sure that the levels of particulates and other possible contaminates stay within specific guidelines. In this situation, the renovations would be happening during the operation of the facility, but the requirements from each code support one another in ensuring patient safety and containment of renovation work.

For "Infection Control" the AIA Documents discuss the need for specific filters on mechanic systems, isolation requirements, and material use. These all support the requirements under CMS (and indirectly under the CDC) to reduce the risk of transferring infections through a healthcare facility and maintaining a safe and healing clinical environment.

A gap that can possibly affect the design is that even though the mechanical air requirements are covered for different spaces within a hospital, there was no noting of design of medication compounding rooms in the AIA or IBC. This is covered in the USP 797, though may not be known by an engineer or designer. If designer is familiar with healthcare standards and the hospital administration is part of the design team, this should not be missed, though going from a strict "design code" point of view, the gap does exist.

Incorporating Standards into information management

The purpose of the standards analysis and comparison was to gain an understanding of which codes cover certain aspects of facility operations and performance. This will be used as part of a proposed healthcare facility information framework. The standards are incorporated into the framework to help determine proper procedures to follow during facility related events. Within FM operations of a healthcare facility, the standards are mostly met through the use of automated building control systems, sensors, regularly

scheduled activities, and knowledge of the standards that need to be met by a knowledgeable professional whose job is to maintain compliance.

As part of existing systems, environment conditions are often monitored by using building automation software such as Johnson Controls' Metasys (Johnson Controls, 2011) or Notifier by Honeywell (Notifier, 2011). Metasys consists of an automated system of sensors throughout the building that are connected to a computer system that tracks the allowable temperature and humidity ranges permitted for different areas of the hospital. The system also allows centralized controls to set different environmental conditions through the building. It also allows a graphical view of system components where sensors are located to check status on room pressures, fan speed, and damper openness. Similarly for fire protection systems, Notifier is an automated system connected to sprinkler, smoke detectors, pulled alarms, and fire control valves. This helps the building operations personnel quickly locate alarms within the facility. These systems help to locate facility problems but do little to aid in the response and ensure that protocols are followed.

In order to more adequately support the response to facility events, aspects of the code need to be incorporated into the framework for responding to different types of events. These areas of the code, as identified through the completed analysis, are included in Table 8.

Table 8: Aspects of Code for Inclusion in Framework

Code	*Information*
JC – Env. Of Care	• Risk assessment and safety protocol in place • Emergency Operation Plan • Preventative Maintenance
CDC	• Water related emergency recovery and remediation • Airborne contaminate emergency remediation • Air quality requirements for repair/renovation • HVAC repair protocol • Water system repair protocol • Cleaning and disinfecting standards after repair/renovation • Infection control risk assessment of event/repair/renovation
OSHA	• Pathogen exposure mitigation
EPA	• Medical waste disposal • Waste water disposal
FDA	• Drug and food refrigeration controls • Replacement supply/equipment standards
USP 797	• Cleaning and disinfecting standards after repair/renovation • Air quality requirements
IBC	• Construction safeguard requirements for repair

Not all of the standards and regulations will be used for every event, only the type of events that are relevant to them. For instance, in the water incursion case in the sample problem within the introduction, the basic response includes containing the water that is leaking from the ceiling, determining where it is coming from, shutting down the system, and then conducted the needed repairs to the system and to the materials that were damaged by the water. In this case, the Emergency Operation Plan which contains information related to the JC – Environment of Care document is followed for water incursion. Since it is a water incursion event, the CDC recommendations are followed for system repair and emergency recovery to limit the patient safety threat caused by the event. Other areas of the CDC recommendations are included for repairing the mechanical system that was determined to be the source of the water. As the repairs are taking place to the system, they needed to be properly cleaned, referencing the CDC recommendations. With the repairs to the affected walls, ceiling, and floor construction safeguard requirements are followed from the IBC, as well as the cleaning and disinfecting requirements listed by the CDC. Lastly, air quality testing is completed as referenced by the CDC.

As it is presented with the studied case, not all standards are referenced for every situation. Other events would require the use of additional references to the standards. It is also possible that through the development and expansion of the framework for more uses that other information from the analyzed standards outside of those listed in Table 8 may be needed.

Summary and Conclusion for Healthcare Facility Guidelines and Standards Analysis

The analysis was completed to gain a familiarity of what is covered within the codes, examine the extent of each document, and get an understanding for the vast amount of regulations and standards that exist as references for facility management personnel in healthcare. There are numerous resources that facility managers must at least have a familiarity with and no one central place for all healthcare environment management information. The analysis gives an understanding of the complexities of healthcare regulations related to the operation and performance of a facility. This understanding can help future research efforts with healthcare facility management. It is important to have an understanding of performance requirements in order to ensure any developed system incorporates the information to fully support facility processes.

2.4. Product Model and Ontology

Formally, a product model is an object-oriented data structure that formally classifies information to support a data exchange mechanism (Eastman, 1999). As part of the product model, an ontology is used as a data exchange mechanism to defined the role of different information and data. An ontology, within information systems, is an explicit specification of a conceptualization. A conceptualization is best

defined as a body of formally represented knowledge, such as objects, concepts and other entities that exist in an area of interest that is being represented (Gruber, 1993). For this research an ontology is looked at as a representational vocabulary specific to a domain, to structure knowledge and exchange information of the domain (Chandrasekaran, Josephson, and Benjamins, 1999), the domain being facility management information within healthcare environments. The storing of the structured knowledge is done by using a product model.

Ontologies are commonly developed to share a common understanding of the structure of information among people and software agents, enable reuse of domain knowledge, to make domain assumptions explicit, to separate domain knowledge from the operational knowledge, and to analyze domain knowledge (Noy and McGuinness, 2001).

Within an ontology, the vocabulary defined is then used to concisely answer queries about the knowledge base using a developed logic within the ontology. The ontology vocabulary, representing the different agents of the knowledge base, then serves as a conceptual schema of data organization within a product model. Each vocabulary term, representing a class of the data structure, needs a clear definition stating the necessary conditions of the class membership. The definitions help ensure a consistency among instances of the class. Another layer of terms, or classes, is relationships. Relationships can be constraints between classes or an argument within a class definition (Gruber, 1993).

Noy and McGuinness (2001) suggest a framework for creating an ontology. The first step is to determine the domain and scope of the ontology. This is important not only to have a clear understanding of what is to be done, but it will guide the ontology development and the way the knowledge base is represented within the product model. In determining the domain and scope questions like: What is the domain that the onology will cover? For what we are going to use the ontology? For what types of questions the information in the ontology should provide answers? And Who will use and maintain the ontology? should all be answered.

Another method to help determine the scope of the ontology and product model is through the use of competency questions. *Competency questions* (Gruniger and Fox, 1995) help to limit the scope. They are questions that should be answerable by querying the ontology and product model. By answering competency questions, the needed level of detail or method of representation of a particular knowledge area can be defined.

The second step as suggested by Noy and McGuinness (2001) is to consider reusing existing data structures. This can include extending a formalism that has been created by adding new features or using

an existing model as a sub-model to a new formalism. The third step is to enumerate important terms. This is the step where the vocabulary terms are thought of and defined. These vocabulary terms will then become the classes within the classification. The classes then need to be organized into a hierarchy with defined relationships. Once the hierarchy is defined, the properties of each class, or slots, need defined. Finally, the slot types need definition. Once these steps are complete, instances of the classes are needed to start creating the actual knowledge base within the product model that the ontology will query and manage.

Development Languages and Tools

In the development of product models and ontologies there are different designed standards that allow for documenting and notating the information. Unified Modeling Language (UML) is a common format for developing objects oriented classifications and software tools. UML is defined as a family of graphical notations backed by a single meta-model that helps in describing and designing object oriented systems (Fowler, 2004). UML is software language independent and is used to organize the design of the systems. Final development of a software language would need to be completed in formal programming language such as JAVA Script or C++.

Within UML there are different methodologies for documenting information transfers and describing information classifications. Not every method of documenting information is needed for any particular project and the methods used would depend on the design of the system, the design team, and the development process (e.g. waterfall or iterative) (Fowler, 2004). Some of the more common methods of documenting the information transfers are Class Diagrams, Sequence Diagrams, and Use-cases.

Class Diagrams describe the static structure of a system. They do not show how the system behaves. Class diagrams consist of classes (representing objects) and associations (representing relationships between objects) (Alhir, 1998). The classes within the diagram are broken into three sections, the name of the class (in bold in the top compartment), its attributes or properties (in the middle), and operations performed by the class (Fowler, 2004). UML Class or Classification Diagrams are used to show the data structure and relationships between different objects within the product model.

Sequence Diagrams are used to show the interactions of classes and information exchanges during operations. They show how the interactions of the system, classes, and their attributes behave with information exchanges (Alhir, 1998). Sequence diagrams one implementation of the scenario that occurs within the system. Multiple sequence diagrams are needed to show the various implementations a system can handle. Sequence diagrams show when classes are activated and operations are in process. They also

show the messages that are passed between objects to get needed data for defined operations (Fowler, 2004).

Use-cases are used to describe the interactions between an actor (user or another system) and the system (Fowler, 2004). They show the functional requirements of a system by showing very detailed step by step actions that need to be completed within a scenario. Use-cases also allow for incorporating foreseeable variations within the scenario should the ideal scenario not be completed.

UML allows for the representation of the product model and the system interactions and data exchange definitions of the ontology. The UML Classification or Class Diagrams show how the data is structured and stored with formal relationships. The Sequence Diagrams define how data exchange scenarios are completed within the system while Use-cases define scenarios between the system and outside actors.

Building Product Models

Two of the most popular and current product model based initiatives that are used within the AEC industry to manage facility information are Industry Foundation Classes (IFC) and the Construction Operations Building Information Exchange (COBie).

IFC is a standard for organizing facility information within a data model. The schema is designed to hold information covering the different disciplines involved through designing, constructing, and operating the facility. The schema is used to transfer information between proprietary software platforms and exchange information. The IFC format is registered by ISO as ISO/PAS 16739 and is being processed as an international standard. IFC is managed by buildingSMART, a model support group that works toward defining and refining the IFC standard and making sure it keeps up to date with industry needs. It is considered an 'Open' format as it does not belong to a single software vender and is neutral and independent (buildingSmart, 2012).

A separate AEC industry initiative is COBie. COBie is a developed standard for capturing and exchanging facility related information throughout the lifecycle of the facility for use during the operation and maintenance phase of the facility. COBie information is documented as it is created and updated through design and construction for use during facility management. COBie is viewable and editable in different formats. It is able to capture and manage information from IFC compliant files or through the use of spreadsheets. The COBie data can also be formatted directly into asset and maintenance data (East, 2012).

Facility Lifecycle Ontology

Ontologies within the AEC/FM industry have been used with IFC models and indexing of element interactions (Vanlande, Nicolle, and Crus, 2008), tying facility information to IFC models (Schever, et.al., 2007), and connecting field issues and information for other domains to IFC models (Petrinja, Stankowvski, and Turk, 2007). Ontologies have also been developed for querying IFC models for partial model analysis needs (Katranuschkov, Gehre, and Scherer, 2003) and query specific information for export in XML format (Zhang and Issa, 2011).

Other uses of ontology in the AEC/FM industry include managing managerial knowledge though a semantic system to acquire, cleanse, transform, index, update, and share construction knowledge though a formal representation of domain knowledge (Lima, El-Diraby, and Stephens, 2005), verifying consistency of computer interpretable material during the construction process (Staub-French and Nepal, 2007), documenting estimator rationale, actions, and knowledge during estimating to support later construction processes (Straub-French, et.al. 2003), and for managing context-sensitive construction information (Wang, Boukamp, and Elghamrawy, 2010). Ontology has also been used for defining formal relationships and capture techniques and methodologies in BIM development (Succar, 2009).

In early lifecycle phases BIM is combined with ontology to help with design reasoning in space programming and sizing of rooms (Kim and Grobler, 2007). Ontology and BIM have also been examined for documenting information from pre-construction activities for reference through the lifecycle of the construction phase of a project (Lee et.al., 2008).

Tsai et.al. (2009) examine the use of an ontology-based service composition framework and BIM to allow for real time data and decision processing during that operation of the building. They tie current temperature reading, sensor readings, and alarm systems to the BIM to allow for real-time and immediate calculation and response to situations. The responses are based on the developed framework.

Difficulties mentioned within the use of the previously developed ontologies in their use with facility management and lifecycle information are limited ability to manage evolution of data effectively and translating information (especially in the facility management phase) (Vanlande, Nicolle, and Crus, 2008).

Within the proposed research the ontology will be used to capture, store, and then query different data and types of information to support FM activities. The references shown in Table 9 will be referenced to help influence methodologies used.

Table 9: Ontology Use Summary

	Stage of Research						Actual Use (Process Researched)								
Referenced	Lifecycle	FM Operations	Pre-construction	Construction	Mgmt Knowledge	Versioning	Tracking	Query	Translating	Change Mgmt	Classification	Knowledge Mgmt	Data Acquisition	Model Changes	Reasoning
Vanlande, Nicolle, and Crus (2008)	X							X	X	-					
Schevers et.al., (2007)	X						X	X							
Staub-French and Nepal (2007)				X					-		X				
Lima, El-Diraby and Stephens (2005)					X			X	X			X	X		
Peutrinja, Stankovski, and Turk (2007)				X		X		X					X		
Katranuschkov, Gehre, and Scherer (2003)				X										X	
Straub-French, Fischer, Kunz, and Paulson (2003)				X			X			X	X		X		
Tsai, et.al. (2009)		X					X								
Kim and Grobler (2007)			X												X
Lee, et.al. (2008)			X				X								
Zhang and Issa (2011)				X				X							X
Wang, Boukamp, and Elghamrawy (2010)				X	X							X			X

Healthcare Ontology and Data Models

Within healthcare, ontologies have been explored as a tool to organize and sort through multiple knowledge sources in support of field doctor response (Bobillo, Delgado, and Gomez-Romero, 2008), organizing personal healthcare initiatives (Blobel, 2011), and transfer information between Healthcare Information Technologies (HITs) that use different standards (Imam, MacCaull, and Kennedy, 2007; Iftikhar et.al., 2010; Ryan, 2006).

More relevant to the proposed research are two formalisms underway within the healthcare industry to create a central system for capturing and classifying patient safety events and related information within a structured ontology. These initiatives are the Agency for Heathcare Research and Quality's (AHRQ) Common Format and the World Health Organization's (WHO) International Classification for Patient Safety. These ontologies offer potential interfaces to a facility management ontology. A more complete description and comparison of these two formalisms can be found in Appendix C in the paper "Evaluating the Role of Healthcare Facility Information on Health Information Technology Initiatives from a Patient

Safety Perspective" as published in the proceedings for and presented at the 2011 ASCE International Workshop for Computing in Civil Engineering. This paper is included within this dissertation with permission of ASCE.

AHRQ – Common Format

The Patient Safety and Quality Improvement Act of 2005 established a framework for voluntary submission of privileged and confidential information to be collectively analyzed in regards to the quality and safety of patient care given in a healthcare setting. The idea is to have the information, from different organizations, in a standardized format to allow the aggregation of data to identify and address underlying causal factors of patient safety problems. The information will be stored in a database where AHRQ in the larger scale or individual hospitals locally can then use the data to analyze statistics and do trending of patterns in regards to patient safety events (AHRQ, 2010).

AHRQ Common Formats allows for capturing the information on different incident types. Associated data for each incident is captured and classified in the Logical Data Model. The Common Format also defines use-cases for developers on how to implement the data model. The processes are captured in a flowchart format to assist with development of data types that need to be recorded for each incident. The goal of the Common Format is to support standardization so that data collected by different entities are clinically and electronically comparable.

WHO – International Classification for Patient Safety (ICPS)

The WHO formed a Drafting Group that was in charge of developing the conceptual framework for the ICPS. The framework was validated for multiple languages and approved to fit the purpose, and to be meaningful, useful, and appropriate for classifying patient safety data and information. The framework aims at providing a comprehensive understanding of the patient safety domain by representing a continuous learning and improvement cycle emphasizing identification of risk, prevention, detection, reduction of risk, incident recovery and system resilience (WHO, 2009).

Possible Connections to Existing Ontologies

Potential areas of connections to WHO's ICPS and AHRQ's Common Formats ontologies within the developed research ontology may be for tracking and diagnosing possible causes to patient safety issues. Both ICPS and Common Formats list determining issues in the documented cases. The facility can be a contributing issue for reported events. This information can be used to within the developed research and ontology for tracking potential problems within the facility. Connecting the developed ontology to other electronic health record systems can help existing systems that track infection trends back to completed

work, maintenance, or renovation. These connections will be considered during ontology development where appropriate.

Ontology Comparison

Between the facility information ontologies and those of other phases in construction the flow of information is not very different. The same is true between facility information and those developed for healthcare information. The types of information, however, vary from project to project.

Both facility management and healthcare information ontologies are organizing a specified group of domain knowledge with a defined scope. The purposes of the ontologies as listed earlier in this section, cover capturing, managing, retrieving, and organizing the types of information. The difference in working with healthcare facility information technology is that the knowledge domain is different in scope than the other mentioned projects. The ontology will still be used for capturing, storing/managing, and retrieving information.

2.5. BIM in Healthcare and Facility Management

BIM has been used for FM operations with limitation and challenges as an as-built data storage tool (Geodert and Meadati, 2008). Some research areas being looked at are BIM as computational based system performance prediction tool to aid in long term and preventative maintenance planning (Lavy and Shohet, 2007; Hao, et.al., 2010), as-built data capture of existing building structure for use in facility management, building extension planning, and energy analysis (Woo, Wilsman, and Kang, 2010), using laser scanning point-clouds to automate the creation of as-built BIM for FM use (Tang et.al., 2010), and computational support for managing change in BIM (Akcamete, Alkinci, and Garrett, 2000).

BIMs use specific to healthcare has mostly been used as a coordination tool to coordinate systems (Khanzode, Fisher, and Reed, 2008), for visualization, and energy analysis (Sheth, Price, and Glass, 2010). It is also explored as an option to be combined with lean and green principles to improve product, process flow, and information coordination efficiencies to deliver better healthcare facilities that run efficiently and effectively (Enache-Pommer et.al., 2010). The use of BIM for healthcare refurbishment has also been examined to see BIM technologies can support the various drivers of healthcare refurbishment (Sheth, Price, and Glass, 2010).

Lavy and Shohet (2007) explore the use of an artificial intelligence based decision support and prediction model linked to a BIM to aid in projecting maintenance costs, plan maintenance events, and project system, facility, and component degradation of healthcare facilities. Similarly, Hao et.al. (2010) investigate connecting asset information, maintenance information, and lifecycle condition-based

information in a BIM with real-time conditional-based information to adequately plan maintenance to reduce interruption in facility operation.

Using BIM for coordination during design and construction does have specific benefits to healthcare in particular besides the inherent complex systems that are present in healthcare facilities. Khanzode, Fischer, and Reed (2008) summarized the benefits of using BIM and Virtual Design and Construction (VDC) technologies while coordinating MEP work on healthcare projects as saving time, creating a safer delivery process, more accurate details and coordination, and saved money with reduced work orders. Ospina-Alvarado and Castro-Lacouture (2010) also suggest that modifying the project delivery to include all players early on will allow the inclusion of needed information to be incorporated into a BIM. The main benefit of the integration can be a detailed and accurate schedule that accounts for all parties' needs, draw information directly from the model, and will bring the project in on schedule and budget. Benefits to the owner were also recognized with changes in organization structure to enhance collaboration with BIM (Dossick, Neff, and Homayouni, 2009).

Akcamete, Alkinci, and Garrett (2009) explore the use of BIM and change management to support construction and facility management. They suggest the use of computational tools to aid in keeping track of changes and making changes to the model. Fruchter, Schrotenboer, and Luth (2009) have shown a benefit of being able to identify the changes that were made and history behind the decision by connecting multimedia information to objects within a BIM that pertained to the history of their develop and change. Both have discussed the importance of an updated information model to support the construction and facility management processes.

Goedert and Meadati (2008) describe the challenges of extending BIM into the construction process to create a single repository of facility data for the owner. A case study project was developed to use existing commercial software to capture as-built data, construction schedule data, and store construction documents and identify the challenges and barriers in the process. The challenges include an additional cost for including information and a level of detail that facility management could use that typically is not included in the model. Interoperability of systems, especially with document collections, was also an issue because different programs were needed to document different types of information. Existing BIM software parameters did not count for FM needs so these parameters were customized and any external data was linked through URL to the objects within the model. Through the entire process it was difficult to quantifiably measure results.

Other efforts are being explored with a goal of reducing the time and cost of creating as-built BIMs by examining the capabilities of technologies to automate the BIM creation process from laser-scanned point

clouds. Some of the largest barriers are a lack of technology available for spatial, topological, and direct relationships and object recognitions. System framework for automating the process includes the use of existing knowledge (models, plans, etc.) to help the system make intelligent decisions and try to breach these barriers (Tang, et.al., 2010).

Table 10 shows a summary of the use of BIM to support facility management.

BIM used within FM operations is mostly as a document container, it helps organize information and data for access. There is limited support as discussed through the research from previous phases of the lifecycle in supporting FM activities. Many of the research efforts, such as Goedert and Meadati (2008), Woo, Wilsman, and Kang (2010), and Tang, et.al. (2010), examine documentation methods to ensure that FM has accurate building data within the BIM. Khanzode, Fischer, and Read (2008) Fruchter, Schrotenboer, and Luth (2009) examine collaboration methods to improve information exchange through various lifecycle changes. Other's document the information as it happens to make sure that there is a clear record of construction document (Fruchter, Schrotenboer, and Luth, 2009). Lastly, others look at using BIM for change management during construction and FM (Akcamete, Alkinci, and Garrett, 2009).

Table 10: BIM support of Facility Management

	As-built data BIM	Lifecycle Coordination	Facility Operation	Facility Renewal Cost	Collaboration	Laser Scanning/BIM	Schedule	Manual Model Change	FM Documentation	Coordination	Performance Prediction	Change Management	Automated Recognition
Goedert and Meadati (2008)	X					X	X		X				
Woo, Wilsman, and Kang (2010)	X					X		X	X				
Khanzode, Fischer, and Reed (2008)		X			X					X			
Lavy and Shonet (2007)			X	X							X		
Akcamete, Alkinci, and Garrett (2009)		X										X	
Ospina-Alvarado and Castro-Lacouture (2010)		X					X						
Fruchter, Schrotenboer and Luth (2009)		X			X								
Hao, et. al. (2010)			X	X							X		
Tang, et. al. (2010)	X					X							X

Summary and Observation

The proposed research looks at linking the capturing of specific information throughout the lifecycle of the project to support FM. It will serve as a repository for FM related information that can be used to aid in planning and respond to FM events. The goal of the BIM based system is to maintain an accurate databank of lifecycle information, update relevant information during FM operations, and allow for a quick access to the information when it is needed.

Most uses of BIM specifically look at one phase or stage of the facility's lifecycle and look at information needs, workflow support, or collaboration within a singular stage. The research differs from other methods by specifically looking at FM information needs in developing an ontology to capture information throughout the lifecycle of the project in the needed format to support FM activities. The information captured and connected to a BIM will allow for a more efficient response to safety events and improved maintenance operations by having relevant information on hand and readily accessible.

3. CASE ANALYSIS METHODS FOR IDENTIFYING INFORMATION LINKS

3.1. Introduction

The proposed framework aims to offer a more efficient method for managing the information to allow facility management personnel to effectively respond to emergency situations. In order to develop the framework there needed to be an understanding of the types of information needed during the response to events. Case study analysis methods were used to determine the types of information in preparation for developing a product model and ontology that can serves as the main information management mechanism within the framework. This chapter discusses the case analysis methods that were used in determining information needs to support facility management response within documented case studies. This chapter also discusses the different links that were defined between facility information and clinical information within the case studies.

3.2. Identifying Facility/Healthcare Information Needs through Case Study Analysis

Facility management and clinical staff of a 500 bed facility with nearly 27,000 annual admissions and over 700 doctors and 2000 nurses on staff were interviewed to determine possible scenarios that may occur within the healthcare facilities pertaining to facility management related events. Case studies of selected scenarios were developed to help understand current facility processes in dealing with facility management events within the healthcare setting. Case scenarios, or sketches of user activities, helped frame an understanding of work practices. The scenario topics received through the interviews were formed into a list of planned and unplanned events (Table 11). Planned events are considered events that can be planned for, such as regular routine maintenance. Unplanned events are emergency and unforeseeable situations that would require immediate response. Each possible event was also categorized based on the amount of time (Y-Axis) it would take to be resolved from the time it was noticed until the time it was resolved. The time categories were determined through interviews with industry professionals. *Short Term* problems are situations that occur with minimal damage and can be resolved in a relatively short period of time. These types of events also have minimal or short term effects on clinical operations. They can typically be resolved by facility management personnel without major disruption to clinical operations in the event location. *Mid-Term* events are those that take more than 4 hours but less than a week to resolve. These events typically have some level of effect on clinical operations and involve a higher level of facility management personnel intervention. Lastly, *Long Term* events take more than a week to resolve. They usually have a larger effect on clinical operations and require major intervention by facility management and clinical personnel. These types of events cause a major disruption to clinical operations in the affected areas. They can also require finding alternative

locations for treatment and services to be offered as continuing clinical operations in these locations may be deemed unsafe for patients until the events are resolved.

Table 11: Case Scenario Topics (developed case studies are highlighted in bold)

	Planned	Unplanned
Short Term (< 4 Hours)	Changing Filters and Cleaning Coils	Interior climate/temperature problems Power Outage Pressure changes in pressure environments Limited Utility Capacity Clogged plumbing – small fixtures
Mid-Term (4 Hours < 1 Week)	Room Renovation - New paint, wax/seal floor, etc. Equipment Renovation Planned Maintenance – Limited Utility Capacity	Chiller goes offline Disease spread/Contaminated air units Boiler goes offline **Malfunctioning HVAC unit in Operating Room** Roof Leak Pipe Burst Knock off sprinkler head while cleaning Sewer backup
Long Term (>1 Week)	Unit Renovation Power strip replacement /Electrical renovation	Mold or moisture damage found during renovation **Chiller pipe burst/Air conditioning shutdown**

Case Scenario Summary

For the purpose of this research and initial systems development, scenarios related to mechanical systems failures that had an impact on patient safety and clinical operations were examined. The case study developed for further analysis and discussed in this chapter is title "Malfunctioning HVAC unit in Operating Room", this is an unplanned mid-term event meaning it was an event that was unforeseen and not planned for that took more than 4 hours but less than 1 week to resolve. A second case, title "Chiller pipe burst/Air conditioning shutdown", was also analyzed. This event was also unplanned for and had a long term effect on clinical operations taking more than a week to resolve. In these cases, patient safety was threatened by the failures of mechanical systems. The cases were analyzed because of its high level impact on the patient and clinical services. The cases involves water incursion, which is a major concern for hospitals and patient safety. Water incursion and mechanical system maintenance are major contributors to the safety of the physical healthcare environment and can be the source of many infections and airborne pathogens (Lutz, et.al, 2003; McDonald, et.al, 1998). The case analyses were completed to

gain an understanding of the types of information that are needed in responding to facility emergencies involving mechanical systems. The case scenarios were first documented as narratives before they were analyzed.

3.3. Case Study 1: Malfunctioning HVAC unit in Operating Room

Water incursion poses a serious threat to the health and well-being of patients and staff. Water, whether clean or grey, and wet surfaces have the potential to harvesting mold, which can become airborne, leading to health problems and possible infection. A case of water incursion into an operating suite was examined.

Case Narrative

Location: Operating Suite and Sterile Storage

Problem: Water incursion from malfunctioning HVAC unit

Players (persons involved): Operations and Maintenance, Building Operation Center, Infection Control, Risk Management, Operating Services, Safety, Administration, Nursing, Security Personnel, Maintenance

Situation: Early in the morning during the weekend, a critical situation arose when the air-handler unit, located over the sterile storage which serves an operating room suite within the hospital, malfunctioned. Water, from the chiller plant, was being pumped into the unit with a broken pipe. The water overflowed the unit and was noticed entering the ceiling within the operating suite over a corridor and operating room by a member of the nursing staff. By this time water had also leaked through the floor into the ceiling and walls of two Emergency Department bed bays. The situation required immediate mediation and determination of cause of damage before any surgery could take place within the operating suite. Figure 6 shows a block diagram section of the affected area.

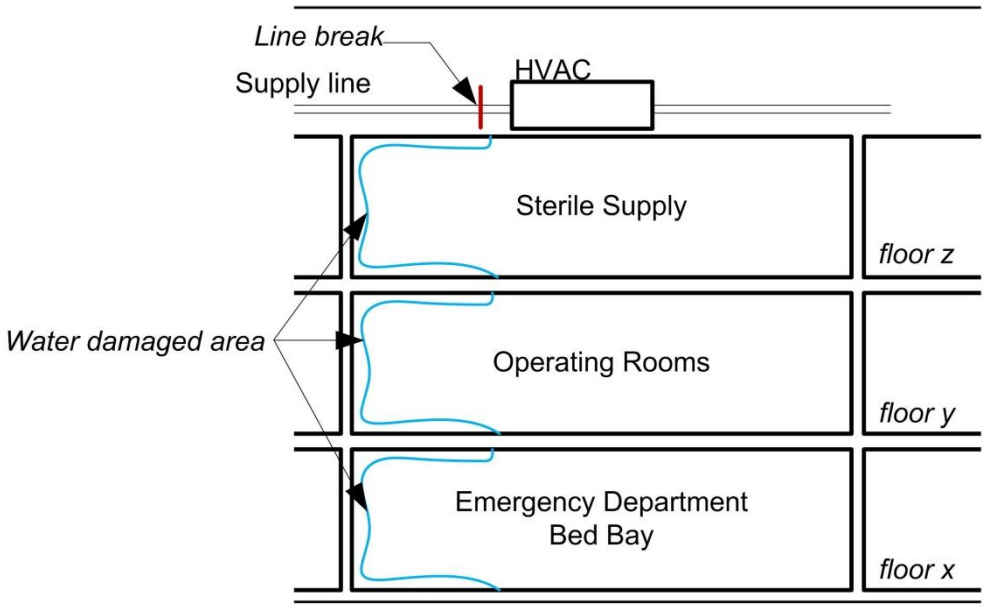

Figure 6: Water Incursion Case Study Diagram – Building Section

Response: The nursing staff member who noticed the incident contacted the Building Operation Center (BOC) Operator. The BOC Operator immediately created a work order, logged the call, and paged the Maintenance Mechanic to the scene. Once the mechanic was on his way to the scene the BOC operator obtained critical information from the person reporting the incident to include in the work order that includes: specific area of facility involved, use of room/space, when did it occur/was noticed, any additional hazards (if so were they or can they be eliminated), extent of immediate damage, is the source of the water known (and what is it), the cause of the problem (if known), has the source been eliminated, what steps have been taken to clean the area, has access to the area been existed, have patient/visitors been evacuated and where are they located, and relevant information. The Maintenance Mechanic would notify the BOC of any critical information when he starts to evaluate the scene.

Once on the scene the Maintenance Mechanic tried to control the situation by containing the water within in containers that were located near the leak. He then started to look in the mechanical spaces above the room to locate the problem. The Mechanic was able to locate the nearest shutoff to the chiller pipe where the water was coming from. Once the chiller line was shut down, the local air handling units were also shut down.

While the Maintenance Mechanic was locating the problem the BOC Operator then dispatched Security Personnel, the Nursing House Manager, and Environmental Health Charge Person to the location. This Level 1 response team will inform the BOC operator what Risk/Damage Level is

assigned to the situation based on previously determined parameters. Once on the scene, the Nursing House Manager assumed Leadership at the scene of the incursion. All persons dispatched conferred on the scene to make the initial determination of the situation and the Nursing House Manager reported back to the BOC Operator. Since the case was in the Surgery/Operating Room Suite, it was determined to be of Highest Risk for Location/Infection Risk Area Criteria with a High extent of damage because the drywall on ceiling and wall was involved with standing water on the floor from the leak, this would place it at a level IV Risk/Damage Incident. The Nursing House Manager reported back to the BOC Operator the determined level.

The BOC Coordinator then determined other personnel to notify to the scene. Immediate actions required eliminating safety hazards, eliminate water source, make appropriate contacts, evaluate patients/staff from the affected area, vacuum standing water, control access to the area and await the Level 2 Response Team. Because of the Level IV Risk/Damage Level - Safety, Infection Control, Facilities, Environmental Health Services, and Administration were notified as the Level 2 Response Team. Since a timeline was not immediately known for making all needed repairs and allowing surgery within that operating suite they had to move planned surgeries to other operating suites within the facility . They also notified other hospitals of the situation that would be used as alternative care sites if emergencies surgeries would need to happen and the operational room were all occupied before the off-line surgical suite was operational.

There needed to be a determination as to how quickly they can bring the OR back up to working level. Care was taken by FM personnel, clinical, and infection control to ensure that the situation was taken care of quickly and fully mitigated. Within this process, FM personnel needed to identify the source of the leak, minimize the extent of damage by taking the system offline, and then repairing the system and all damage.

OR staff had to assess the current environment and determine what needed to be done and how quickly they can do it to bring it back up to work level. Hospital administration made the final decisions on whether the environment was up to JC/DOH standards. They may refer to safety, infection control, clinical, and other personnel and standards.

Total damages in replacing sterile supplies, lost revenue, and contractor repairs were estimated above $7 million.

Location/Infection Risk Area Criteria and Risk/Damage level are defined in the emergency operation protocol within the healthcare organization. Factors such as event type, location of event, extent of damage, and proximity to patients are taken into account when determining these criteria and classification levels. Variations to the case, such as timing of the situation, proximity to patients, and location to certain services were examined during the case analysis.

3.4. Case Study 2: Chiller Pipe Burst/Air Conditioning Shutdown

Air conditioning in healthcare is important to reduce effects of heat and added stress on the body. When there is a major failure within the HVAC system that will not allow for proper cooling, it poses a health threat especially to those with weakened immune systems recovering from procedures or illness. The following case describes the actions taken when a main chiller line ruptures and patient floors and services lose all air condition.

Case Narrative

Location: In-patient care building

Problem: A primary cooling line serving the air conditioning within an in-patient care building broke causing it to go offline.

Players: Nursing, Administration, Facility Operations, Building Operations, Safety, Security, Risk Management, Local Government Emergency Management, Region Hospitals

Situation: During a mid-summer heat-wave of consistent highs of 90 degree weather a primary cooling line breakage caused the air conditioning within an in-patient care facility to go offline. The pipe connecting the central plant chillers to the main campus HVAC system broke. Due to the HVAC system being offline the internal temperature of the building quickly rose to 80 degrees because of the intense heat outside.

Response: A member of the nursing staff notified the Building Operations Center (BOC) operator of the unit being too warm. The BOC operator completes a work-order of needed information and dispatches the maintenance mechanic to the unit to evaluate the situation. The maintenance mechanic notices that the HVAC is not working correctly, when he goes to explore possible solutions, he notices water leaking from a chiller pipe in the basement. The mechanic immediately notifies the BOC of the leaking water and then finds a nearby shut-off valve to turn off the water. He also shuts down the HVAC of the building that is supplied to limit further damage.

The BOC operator, with the report of water incursion dispatches the nursing manager, security personnel, environmental health services person, and administrator on call to assess the scene. The response team assessed the problems and determined the different threat levels. The nursing manager then notified the BOC operator of the situation. Based on the Emergency Operation Plan the BOC operator dispatched additional personnel to the scene. These personnel included additional facilities personnel, infection control personnel, safety personnel, and additional environmental health services personnel. Meanwhile, facilities started to repair the pipe. The first priority was to fix the pipe to supply the building with chilled water and the second to get the air conditioning back up and running. To properly access the pipe, portions of the wall and ceiling needed to be removed.

The timeline to get the air conditioner back up and running was unknown so the administrator on call and nursing manager made the decision to evacuate all patients to alternative care sites because of the extreme heat conditions. All other clinical activities with specialized equipment and supplies needing temperature control were canceled and appointments were rescheduled. Any critical appointments were moved to other facilities. In secondary buildings where doctors had office and some clinics were located the air condition was working properly and not affected by the line break. These services were left operational and not directly affected by the evacuation.

The evacuation plan was put into place by administration and nursing and coordinated with the local government emergency management office to ensure transport for patients. Patients were relocated to other facilities based on each individual's care needs and the availability of care from other regional hospitals. Patients were moved by ambulance to other care facilities. Protocols were put in place to ensure that the patient information was available to transportation personnel and the facility they were transferred to. The patients who were cleared to go home sometime during the day were discharged and not relocated.

Outcome: It took two days to properly repair the pipe. The air conditioning system was back on-line one day after the pipe repair. It took several days to re-cool the building to a safe level to fit within healthcare services. Due to extreme outside temperature it had to be done slowly as to not overwork the systems. Since the system was down for so long with high humidity and temperature, it also took several days once it was cooled to sanitize systems and make sure that the moisture and heat did not cause any additional problems. A roomful of supplies that were temperature sensitive needed to be discarded and replaced due to the raise in interior temperature.

Outpatient clinics were fully restored in two days when the pipe was replaced and their air conditioning was turned back on. The emergency department also took limited walk-ins. The in-patients were relocated for over a week as the facility was restored to normal.

3.5. Case Scenario Documentation

The flows of events described in the narratives were documented as process models using Business Process Modeling Notation (BPMN). BPMN allows for the understanding of individual tasks and decisions made by each actor or personnel group in a standardized representation format. Figure 7 shows a BPMN of the "Malfunctioning HVAC unit in OR" Case-1 scenario. (Complete BPMN descriptions are included in Appendix D and E.) The process model was completed as the base scenario of the documented case showing each task and decisions as described through the interviews and literature review. The process model was reviewed by healthcare facility management staff for completeness, accuracy, and representation of policy procedures that would be used during the events.

The process model was first documented as a higher level with main activities. Once the general format was sketched out, the main activities were then divided into the representative tasks and actions that offer a more detailed visualization of what happens throughout the process. The main activities at a higher level are represented within Figure 7 with a dotted rectangle around a group of more detailed individual tasks or actions.

Each individual task or action is represented by a rounded rectangle. These tasks are placed into swimming lanes (long horizontal rectangles) under a location (e.g. Mechanical Service Room) or a group of actors or personnel (Nursing Staff). Solid arrows between tasks represent a direct connection of activities. When one task is complete, the next is able to occur. An example of a direct connection is under "Nursing Staff," as soon as the nurse notices the water in the action "Noticed water incursion by staff" they are to complete the task "Notifies BOC of Problem". A dotted line with an arrow, such as between "Notifies BOC of Problem" (in the Nursing Staff lane) and "Receive Notice of Problem" (in the BOC lane) represents a communication or a message sent in the direction of the arrow. In this example, the message is through a phone call from a member of the nursing staff to the maintenance call center. The message type and content is annotated next to the arrow.

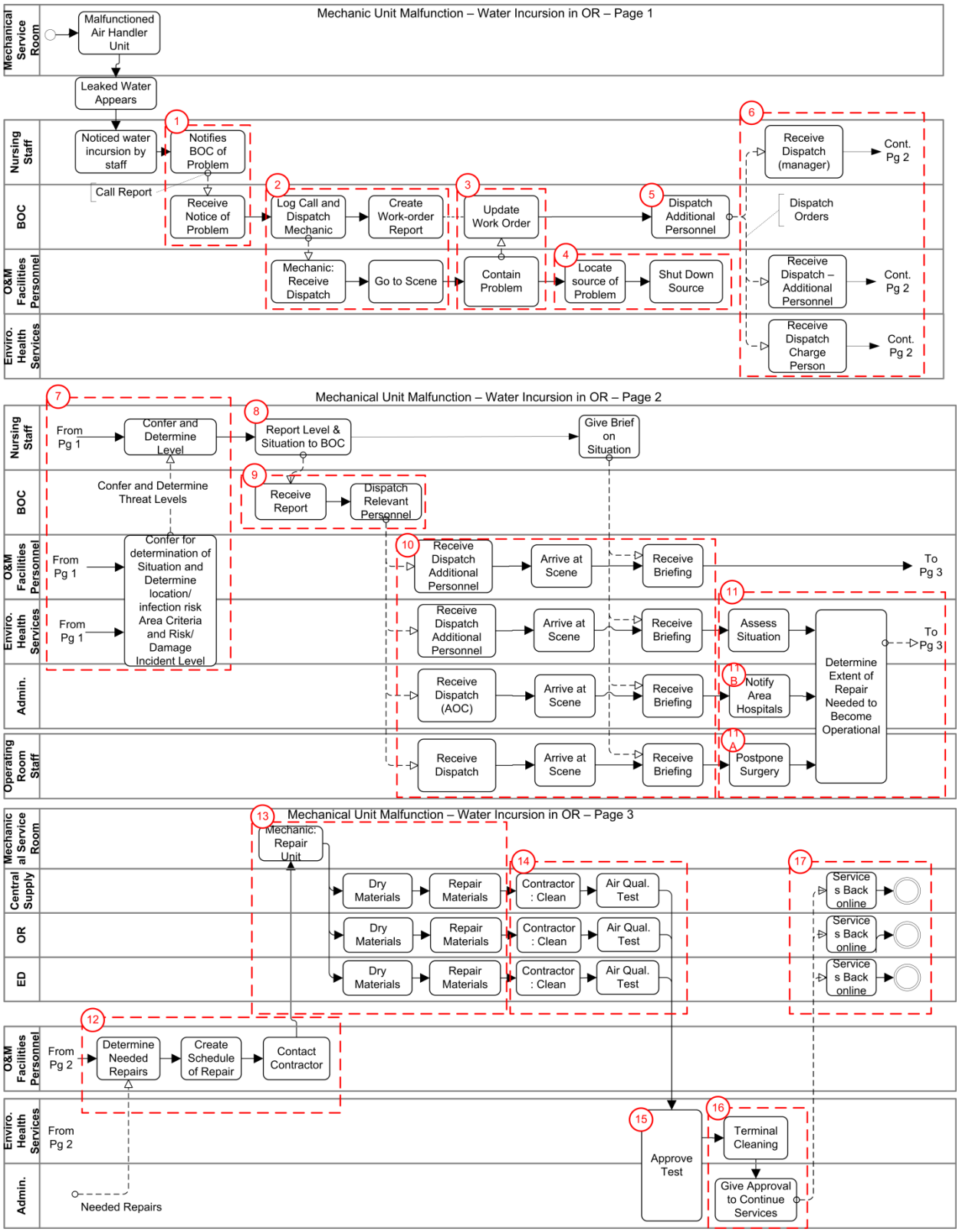

Figure 7: Partial BPMN process model of "Malfunctioning HVAC in OR" scenario

Once the process models were reviewed and completed, Failure Mode and Effects Analysis (FMEA) and Fault Tree Analysis (FTA) were completed to help draw direct links between facility problems and health threats. FMEAs allow for analyzing a system for potential failures and effects associated to each failure. Functional block diagrams are the first step of completing an FMEA and are used to diagram each piece of the analyzed system. Figure 8 shows an example of a functional block diagram of the mechanical system over the operating room suite. The components of the system are numbered to identify different possible failure points and consist of 100: Air Handler, 200: Operating Suite, and 300: Chiller. The Air Handler has multiple parts that may be the cause of a failure so it is expanded on the right of the diagram and contains items 110: Fans and 120: Coils.

Using the functional block diagram as a base, the FMEA table is developed. The FMEA table lists possible failure modes of an examined system, causes for each failure, health effects (or threats to patients) associated with the failure, detection methods, and rankings of each effect by their likelihood of occurrence, detection, and overall severity. The rankings used were "Low", "Medium", and "High". The traditional numerical (1-10) ranking was not used because the less granular ranking allowed for a quick review of the priority of the events and easily conveys their effects on the healthcare delivery process. Table 12 shows a sample of the FMEA table.

The complete FMEA analyses for the case studies are included in Appendix F and G.

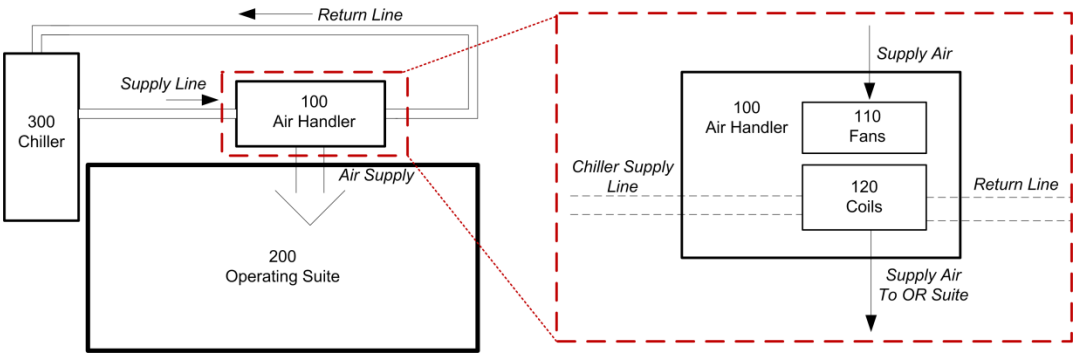

Figure 8: Functional Block Diagram – Malfunctioning HVAC in OR

Table 12: Sample Health FMEA table

Failure Modes and Effects Analysis (FMEA) - Patient Safety

Malfunctioning HVAC in OR

Item No.	*Item*	*Potential Failure Mode*	*Failure Cause*	*Facility Failure Effects*	*Health Failure Effects*	*Likeli-hood of Occur-ence*	*Detection Method*	*Likeli-hood of Detection*	*Seve rity*	*Actions to Reduce Occurrence of Failure*
100.01	HVAC Air-handler	Chiller supply line leak over Janitor closet	leak at fitting/oxi dation and pinhole leak form	water in ceiling material of closet/fix and replace ceiling	Airborne contaminates and mold/mildew	Medium	flow sensor or visual water mark on ceiling	Medium	Low	Regular maintenance of systems
100.02		Chiller supply line leak over non-sterile corridor	leak at fitting/ oxidation and pin hole leak form	water in ceiling material needs to be dried/replaced	Airborne contaminates and mold/mildew - Respiratory problems to patients or other infections	Medium	flow sensor or visual water mark on ceiling	High	Med	Regular maintenance of systems and training to report cases as soon as something is noticed
110.01	Chill. Coil	Coil blocked & backflow leak…	Leaked from blocked coil	Water on ceiling and floor	Staff slip/injury, supplies damaged or contaminate to patient infection	Medium	HVAC Sensor, visual notice of water	Medium	High	Regular Maintenance & training to report cases.
120.00	…	…	…	…	…	…	…	…	…	…

The items in the table are connected to the items within the functional block diagram. For example, item 100.01, deals with 100: Air Handler. The ".01" lists the sub-item, as there can be several potential failures associated with each item. Sub-item 100.01 is the Chiller supply line leak over Janitor Closet with the failure cause listed as "leak at fitting/oxidation and pinhole leak forms". Then two different types of failure effects are listed. The first is the Facility Failure Effect, which is water in the ceiling material which needs to be fixed or replaced. The second is the Health Failure Effects which are connected to patient and staff safety. The FMEA took into account different locations within the Operating Suite that the problem may occur. This allows for showing the levels of severity and different effects on clinical operations and patient safety. Different failure causes were also listed for each item. The different failure locations have the largest effect on the process response and level of threat to patient health and safety. The additional modes and causes are important to the creation of the proposed framework and allow for a larger dataset of potential failures and threats. This will help the framework to be more inclusive for mechanical system related events.

The failures identified in the FMEA are used in the FTA. The FTAs allow for tracing the possible causes of each failure to root causes. It also enables the listing of possible prevention methods for each identified root cause. The possible failures taken from the FMEA were connected to one or more possible

causes. Branching off of each possible cause, additional possible causes are listed for each possible cause until a root cause, or determining factor, is listed for each branch of the tree. Connected to each root cause is a possible prevention method. The FTA diagram from the "Malfunctioning HVAC in the OR" case is included in Figure 9. Complete FTA analysis diagrams for both case studies are included in Appendixes H and I.

An example of a chain of events would be a Fault Event of "Water Incursion Over OR Suite". There are multiple potential failure event causes that include "Air Handler Coil Broken", "Chiller Pipe Break", etc. Only one of these has to occur in order for the failure to occur. If it was determined that the "Air Handler Coil Broken" was the Fault Event cause, there are three potential Failure Events that may cause that to happen. These include "Damages from other maintenance", "Corrosion", and "Faulty Joint/Connection". By determining which one of the three occurred, a route cause than then be determined. Associated with each root cause is a prevention method on a way to minimize the potential for each root cause.

When the FTA and FMEA are used together, potential threats within a system can be identified. In the conducted FMEAs the potential failures of physical environment conditions were connected to threats on patient safety. These include the potential for a failure to cancel a needed procedure, or more significantly, if the failure occurs in critical locations of the hospital, the patient and staff are prone to infection and injury. The FTAs were used to help identify causes. The FTAs can be used to ensure preventive work is completed or systems are designed to remove the potential for a threat. In the proposed framework, the FTAs will be used to help with identifying potential causes and with trouble shooting identified problems.

When the FTA and FMEA are used together, potential threats within a system can be identified. In the conducted FMEAs the potential failures of physical environment conditions were connected to threats on patient safety. These include the potential for a failure to cancel a needed procedure, or more significantly, if the failure occurs in critical locations of the hospital, the patient and staff are prone to infection and injury. The FTAs were used to help identify causes. The FTAs can be used to ensure preventive work is completed or systems are designed to remove the potential for a threat. In the proposed framework, the FTAs will be used to help with identifying potential causes and with trouble shooting identified problems.

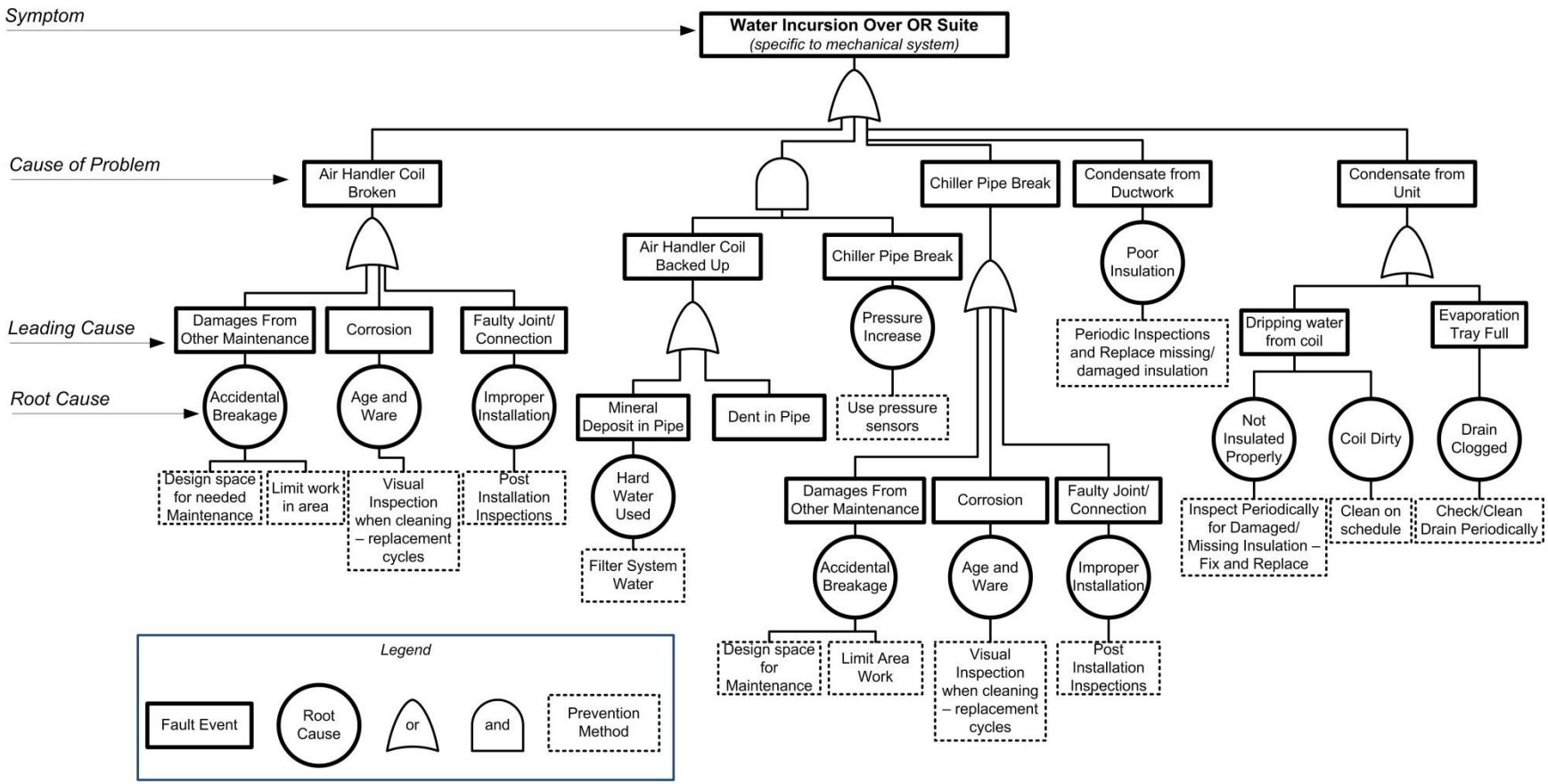

Figure 9: FTA diagram of "Malfunctioning HVAC in the OR" case

3.6. Information Needs Analysis

Unified Modeling Language (UML) Use-cases were developed from the information contained in the process models, FMEAs, and FTAs, and was used as a basis for the information needs analysis. The BPMN process models were used to create the typical flow for the use-cases. The possible faults listed from the FMEAs and causes documented in the FTAs were used in developing the use-case alternative flows. Each use-case flow is documented as a detailed narrative and references communications, other actors, and information that is referenced, transferred or created during the process. Each step of the narrative is a detailed action within the overall use-case. Figure 10 shows a use-case diagram where the operations staff is developing the work schedule for the repair. Use-case Diagrams were generated during the use-case development. These help to show the interaction of the use-case to actors and other use-cases. The actors "Level II Response Team" and "Hospital Administration" have input into the action. It then communicates to the *Mechanical Shop* and *Contractors* and includes the Use-cases "Make Repair to Unit" and "Repair Walls/Ceilings/Floors".

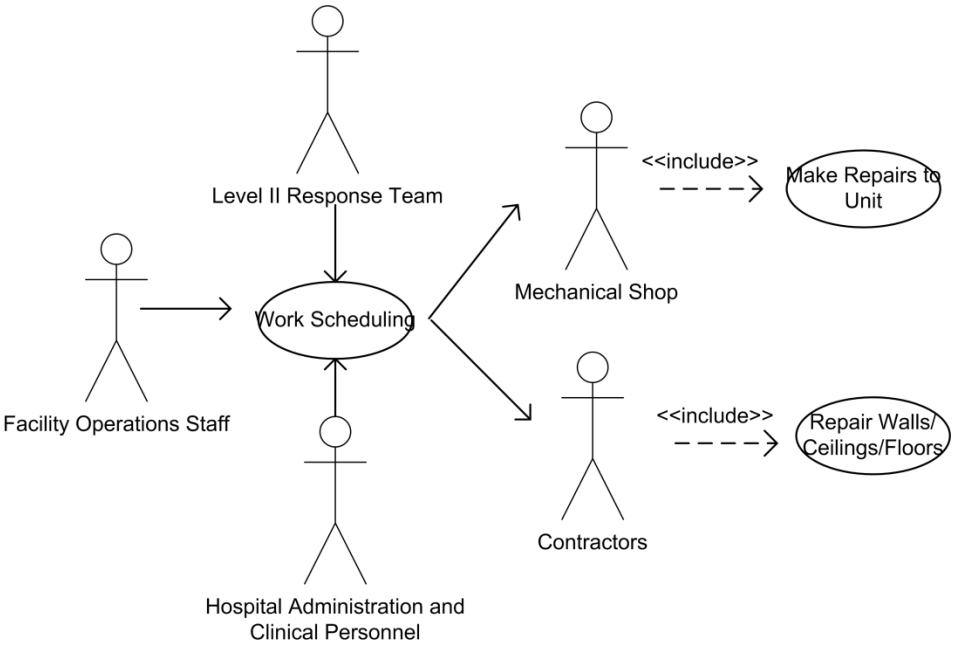

Figure 10: Work Scheduling – Use-Case Diagram

The Use-Case in this case is written as:

1. Facility Operations Personnel review the damages.
2. Facility Operations Personnel receive list of needed repairs to become operations by Level II Response Team.

3. Facility Operations Personnel estimates the time for the repairs based on the wall and ceiling areas that need to be dried and replaced.
4. Facility Operations Personnel create a schedule for repairs and presents it to the Hospital Administration and Clinical Personnel of affected areas for approval.
5. Facility Operations Personnel receive approval of schedule.
6. Facility Operations contact the Mechanic Shop and Contractors needed to make the repairs.
7. Include use-case ***Make Repairs to Unit***.
8. Include use-case ***Repair Walls/Ceiling/Floor*** for the ED, OR Suite, and Sterile Storage Room.

The information types from each step were then documented in tabular format (Table 13).

Table 13: Information Type Documentation

Step	Step	Decision/Procedure	C/A*	Information ID and Type
1	Receives report of leak	1. Log call 2. Initiate Response	1. C 2. A	A. Person reporting call B. Location ID C. Reported Problem D. Emergency Operations Plan protocol
2	Dispatch Mechanic	Dispatch Page	C	Send: B, C
3	Create Report	Open work order	P	Document: A, B, C and E. Responding action F. Work order number G. Date of report H. Time of report I. Use of location J. Preventative actions taken
4	Go to Scene	Respond	C	Receive: B, C
5	Find Source	Visually Inspect/Troubleshoot	A	
6	Call for Sys. Info.	Request information	C	Give: K. System Type L. System Location M. System ID-Tag/Barcode
7	Receive Call	Received request	C	Receive: K,L,M
8	Control (if poss.)	Control – mitigate damage	A	N. Emergency Equipment Location
9	Look up Info.	Find shut-down procedures and areas affected	C	O. Shut-off valve location P. Shut-off procedures Q. Zones affected by downed system
10	Return Call	Return request – call procedures to Mechanic	C	Give: O,P,Q
11	Locate Shut Down	Shut-down system	A	
12	Notify Call Center	Report to Call Center	C	Report: K, L, M, Q R. Initial damage assessment S. Initial problem assessment T. Mitigating Action
13	Update Report	Update work order	A	Include: P, Q, R, S, T
14	Proceed w/ Repair	Dispatch Response Teams	A/C	Reference: D

*C – Communication A-Action

Complete Use-cases and Information Analysis are included in Appendixes J and K.

The individual pieces of referenced information were traced back to their origin. Information that was created was also documented for when it may be used in future activities, whether it is later in the process or later in the lifecycle of the facility. Figure 11 shows a portion of the information tracking that is referenced for the first part of the "Malfunctioning HVAC in the OR" case. The figure relates the information that was identified in Table 13 to the phases of the lifecycle and where the information can be found. For instance, item K, L, and Q all reference information from the mechanical drawings that were created during the concept and development phase. Similarly, the figure shows the information that was created and needs to be stored for future maintenance work or upgrade. These are work orders and notes that will be connected to the drawings. Lastly, clinical policies (vertical communications) are referenced from the clinical operations within the facility (item D).

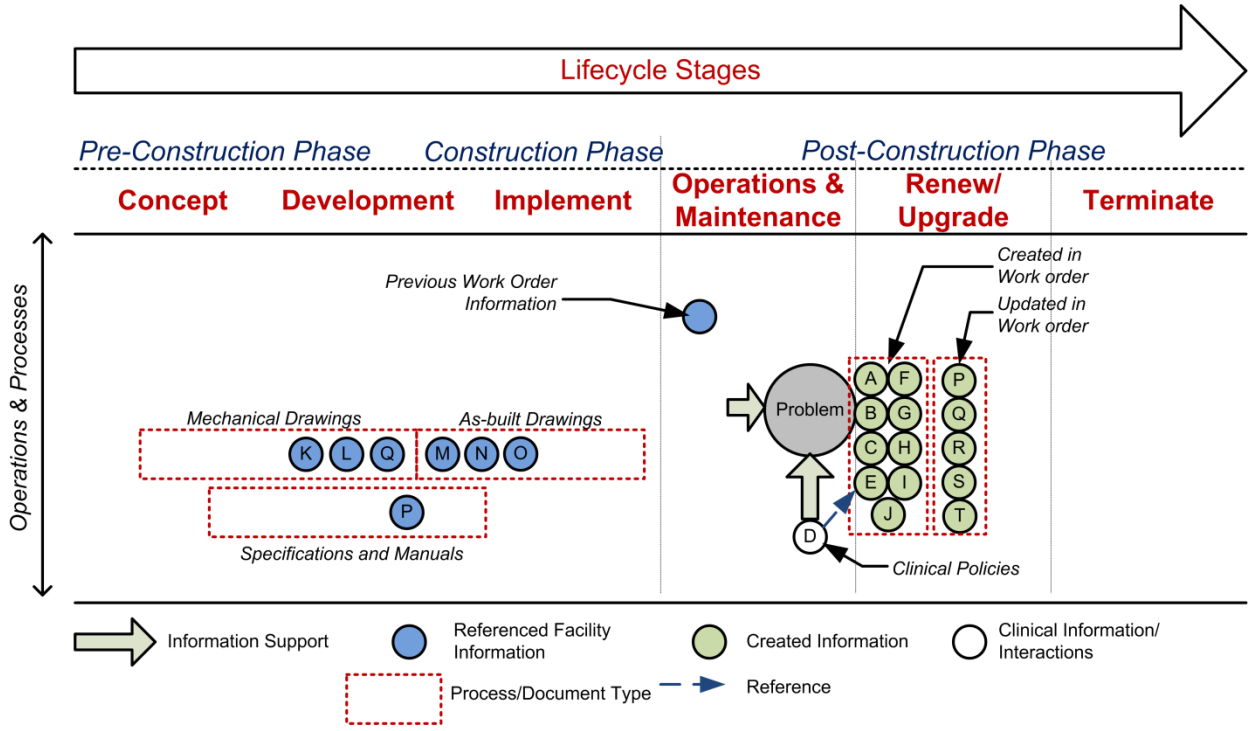

Figure 11: Lifecycle Information

3.7. Summary of Analysis Findings

In this chapter the FMEA and FTA analysis are used to validate the hypothesis made before the analysis was completed by showing that events within the healthcare environment are dynamic in nature. The location and situation have an effect on the response needed as well as the threat to patients. An event can have a varying degree of responses based on its location, clinical service area, and proximity to patients. These varying degrees of response can be classified as "protocols" within the "response". Also connected to the response are clinical and health association regulations and codes that guide the response

that can be classified as "standards". In order to determine the proper type of response, the location of the event as well as the event or problem type need to be classified. The "problem type" includes general situations such as mechanical problems, water incursion problems, or air quality problems. The "location" of the event can be classified within an overall "facility information" classification. Connected to facility information can be possible components for systems that can cause the problem within the space. This would aid with trouble shooting the cause of the identified problem. With this information linked together, based on the case analysis, the proposed framework can efficiently help identify the problem and determine the proper response. The inherent risks or "health threats" can also be linked to the proposed framework. As documented in the FMEAs each failure and problem has an inherent set of risks. When the problem is identified these "health threats" can be linked to the problem to help determine proper mitigation that is needed. The health threats can also be linked to spaces if the problem occurs in a specific location. For the base of the proposed framework the problem, location, and symptoms of the event will need to be identified in order for the response, causes, and necessary mitigations to be determined.

Also identified through the analysis are a series of existing systems that are interacted with during the process. These identified systems can be connected to the proposed framework. Table 14 lists the identified system interactions within the case analyses and the information retrieved or referenced from each of the systems.

Table 14: System Interactions and Information

Systems	Information Referenced
Clinical System Scheduling Systems (e.g. Teletracking) On-Call Personnel	 Room occupancies, patient locations Notifications and pages
Facility Systems Building Automation Systems (e.g. Johnson Controls)	 System Status, Mechanical/Fire alarms, Electronic Alerts

As listed in Table 14, there are clinical and facility systems that are in place and that are used while responding to the analyzed situations. These systems offer different pieces of information vital to initiating the response and determining what steps are appropriate within the response. Table 15 lists additional types of building information, clinical information, and organizational information that are also referenced, updated, or created during the analyzed cases. A considerable amount of the information is currently available in different systems and locations, and requires communications between different personnel. These communications, depending on the urgency of the request and the nature of the work, are currently done through pagers, two-way radios, phone calls, or emails. There is scope for greater use

of automated data acquisition technologies (e.g. sensors) and real-time communication systems that provide instantaneous notifications when systems malfunction.

Table 15: Case Analysis Information Type Summary

Information Types	Data
Building Information	
Construction Documents	Mechanical Systems Information and Specifications
Work orders	Prior work done on system, maintenance performed
Mechanical Zoning	Affected areas for defective systems
Contractor Information	Repair and testing personnel availability
Supplier Information	Replacement part availability
Clinical Information	
Environment of Care Standards	Moisture levels, Air Quality, Temperature and Humidity Standards
Organizational Information	
Emergency Operation Plan	Procedures and notifications for event type response

3.8. Information Findings Support of Product Model and Ontology Development

The findings of the case analysis will guide the product model and ontology development. The product model (Figure 12) will help to sort information, store it within the correct location for quick and easy recall, filter information on user queries, and process information. The ontology will help with the querying, storing, and filtering of data based on the event problem type and location. The identified information sources from the case analysis including the building automation systems (e.g. Johnson Controls/Metasys, and Notifier), Bed allocation and scheduling systems (e.g. Teletracking), and other existing communication systems that are in use within the healthcare facility will also be connected to the product model wherever possible. The basis of the facility data can be collected and maintained based on the formalism defined by the National Institutes of Building Sciences, Who Building Design Guide, Construction Operations Building Information Exchange (COBie) (East, 2012). COBie information is documented as it is created and updated throughout the design and construction with the goal of being used during facility management. The COBie standard allows for a formal method of documenting systems and components of the facility. Additional information can be connected to these components through the proposed product model including possible failure of components, clinical services in designated locations, and response protocol for different problems based on the location and service type.

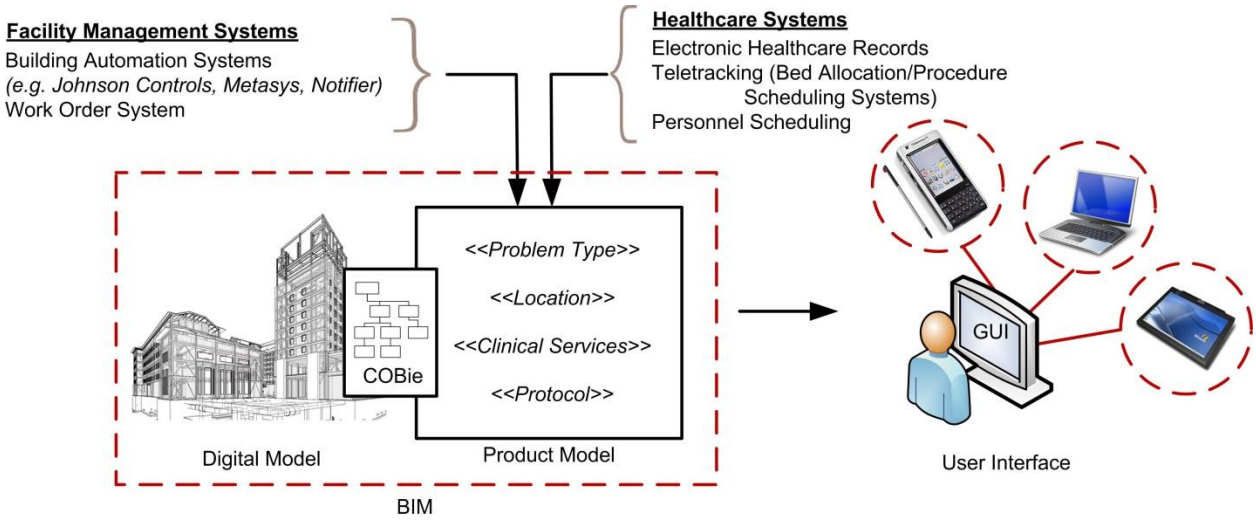

Figure 12: Product Model Connections

3.9. Conclusion

The process models documented in BPMN were used to document the decisions that took place during the response to the event. The process model then served as the base for the FMEA. The FMEA was used to determine variations to the base flow shown in the process model. This allowed looking at how different failures within the system required different responses and caused different threats to clinical and facility operations. The FTA further developed the FMEA information by identifying the root causes of each of the potential failures. From the process model and FMEAs, use-cases were developed. The use-cases were very detailed in nature which allow for an analysis of information needs. The information types that are identified are then used as a basis for creating classes and attributes within the product model. The process models help to identify the information exchange mechanisms that define how the information within the product model acts.

Based upon the preliminary case analyses, a link was defined between facility operations and risk to patient safety. Timeliness and efficiency of response also influence the overall damages and risks associated with any emergency event. The analyses that were completed with the FMEAs and FTAs will aid in development of trouble shooting aids that will enable a maintenance mechanic to diagnose problems when they occur. They allow for linking possible failures to components within the product model. This coupled with the location of a problem, as well as the type of problem that is reported, will allow for immediate and effective retrieval of information to the user to response to the event.

4. A HEALTHCARE FACILITY INFORMATION MANAGEMENT FRAMEWORK

This chapter discusses how the information analysis results from Chapter 3 were used in creating the product model and ontology in completing Objective #2. The case analysis discussed in Chapter 3 resulted in a detailed information analysis from the UML Use-cases. These terms listed in Appendixes J & K for the two case studies were used as the basis for forming a vocabulary term list. The vocabulary terms then formed the different classes and attributes of the product model. The relationships between the different classes were based on the information exchanges needed that were analyzed within the UML Use-cases.

As discussed in Chapter 3, the FMEAs were used during the UML Use-case creation to determine possible alternative flows. These alternative flows led to additional information exchanges that were identified in the information analysis. The FMEAs were also used to help determine associations between systems and different hazards and health threats. These associations are used in defining different instances of the hazards and health threats classes. The FTAs were used to help classify links between systems and the problem type. They allow for tracing different symptoms of problems to a root cause. This information is used in the development of the product model to help diagnose the root problem to a reported event.

The product model is documented as UML Class Diagrams which are documents the static relationships between different classes of information. The information exchanges are documented as UML Sequence Diagrams. The sequence diagrams show the interactions between classes during different operations and how the information is exchanged. The product model is evaluated against a literature based case study to ensure that it is expandable and works beyond the two case studies in which it was developed for. The end user interactions with the product model and how the user can retrieve the information are discussed in Chapter 5 with a conceptual model development of a prototype.

4.1. Introduction

For effective and efficient management of the facility, information needs to be readily available and be able to support the activities that are taking place. The communication, capture and tracking of this information are often fragmented and difficult to manage. The framework is proposed to help more effectively manage facility information in healthcare environments. The framework consists of a Building Information Model (BIM) based system that helps to capture and store facility information for easy recall when needed during the operation and maintenance phase. As part of this framework, an information classification system is needed to manage the information flow. This healthcare facility information management product model is the main focus of this chapter.

Healthcare Facility Information Management Product Model

The purpose of the proposed BIM-based framework is to aid facility managers in the more efficient operation and maintenance of the facility while consistently having to do more with less resources and personnel. The starting point of properly managing the information is a classification system. This classification is the healthcare facility information management product model. The product model allows the tracking, storing and easily filtering and recalling of information to help facility management personnel respond to facility events. Facility events are planned or unplanned, maintenance related occurrences that have a direct or potential impact on patient care and safety. The aim of product model is incorporating the facility information with the clinical information pertaining to patient safety threats and hazards as they relate to potential facility events.

Currently within the healthcare industry there are no information systems that link facility and clinical information to aid in managing healthcare facilities. As discussed in the *Background and Literature Review* there are two separate initiatives to develop taxonomies for documenting patient safety events. These are the Agency for Health Research and Quality (AHRQ) *Common Formats* and the World Health Organization's (WHO) *International Classification for Patient Safety*. *Common Formats* (AHRQ, 2010) is designed to allow capturing of information related to difference incident types. It is established through the Patient Safety and Quality Improvement Act of 2005 to capture voluntary submission of privileged and confidential information to be collectively analyzed in regards to the quality and safety of patient care given in a healthcare setting. The idea is to have the information, from different organizations, in a standardized format to allow the aggregation of data to identify and address underlying causal factors of patient safety problems. The *International Classification for Patient Safety* is a similar initiative by the WHO (WHO, 2009). It is designed as framework that aims at providing a comprehensive understanding of the patient safety domain by representing a continuous learning and improvement cycle emphasizing identification of risk, prevention, detection, reduction of risk, incident recovery, and system resilience. These initiatives help to classify clinical information. The only connection to facility information is if the event was linked to an issue within the facility as the cause.

Outside of healthcare and within the AEC industry, Industry Foundation Classes (IFC) is a standard for organizing facility information within a data model. The schema is designed to hold information covering the different disciplines involved through designing, constructing, and operating the facility. The schema is used to transfer information between proprietary software platforms and exchange information (buildingSmart, 2012). A separate AEC industry initiative is the National Institute of Building Sciences,

Whole Building Design Guide, Construction Operations Building Information Exchange (COBie) (East, 2012). COBie is a developed standard for capturing facility related information throughout the lifecycle of the facility for use during the operation and maintenance phase of the facility. COBie information is documented as it is created and updated through design and construction. These initiatives are both used throughout the AEC industry to manage facility information. The proposed data model takes into account the linking of the facility and clinical information.

System User Requirement Definitions

The product model aims to support the user by capturing, storing, and managing lifecycle information to help identify sources of problems, respond to those problems and conduct the necessary repairs. The system will be supported with a Graphic User Interface (GUI) to allow the user to input, query, retrieve, and store information within the product model. Some of the questions that the product model is capable of answering are listed in Table 16.

Table 16: Product Model User Support Requirements

Framework Function	Questions
Identifying problem	What can cause the reported symptoms of the event? What is the source? Has the problem occurred before and what were the causes? What are the possible causes? We have health threats identified, what might be problem source?
Response	What response is required for the identified problem? Is there a related protocol? How do we mitigate the situation?
Repair	Who is qualified to make the repair? What are the standards associated with the repair? What parts are needed and where can we get them? What are the procedures (drawings, specifications) for doing the work?
Documentation	How was the problem remedied? What work was completed?

Development Cycle

The product model development cycle consists of multiple steps for data and process analysis, information identification, development, and evaluation. The steps were as follows:

1. Process documentation: through meetings with industry professionals, case studies were documented that included the processes facility management personnel take when facility related events occur. These were documented in the Business Process Model Notation (BPMN) format. The process models include interactions with clinical staff and existing building control systems.
2. Case analysis: once the cases were documented as narratives and process models, they were analyzed through Failure Mode and Effects Analysis (FMEA) and Fault Tree Analysis (FTA). These analyses are used for determining alterations to the base flows that were documented. They also allowed for determining possible failures to systems and root causes of problems. Links to patient safety threats were also documented within the FMEAs.
3. Information Analysis: Unified Modeling Language (UML) Use-cases are developed to perform an information analysis. UML is a language that is used to model systems. It allows for specifying, visualizing, constructing, and documenting systems (Alhir, 1998). The Use-cases allow for documenting each individual step of the process allowing for information needs, communications between service groups and interactions with systems to be identified. The FMEA and FTA analyses results were used to develop the use-cases that consisted of the base flow of the process model as well as alteration flows.
4. UML Classification – Product Model: Once the information needs, interactions, communications, and different actors were documented through the UML Use-cases, the UML Classification is developed. As part of the classification, a series of sequence diagrams is developed to document the interactions between the classes that will be used in the prototype development.
5. Test Case Analysis: In order to ensure that the UML classification works for cases outside of those used during the original analysis, additional case studies are developed and input through the product model to make sure that all information needs are accounted for.
6. Conceptual Model Development: The conceptual model is used to demonstrate the interactions of the user with the product model. This is done through the use of a GUI that allows the user to input event information to receive information to assist them with the proper response.

As part of future research, a prototype based on the conceptual model will be developed. The prototype will be used during evaluations with industry professionals is conducted to gauge the usability of the

developed system. After the initial evaluation, a full implementation would be piloted and developed for additional evaluations and validating tests.

Cycle steps 1 through 4 have been completed prior to this chapter. The focus of this chapter is the UML classification process to develop the product model and then the test case analysis used to help validate the product model beyond the cases used for preliminary development. Conceptual model development and analysis is discussed in Chapter 5. Prototype and evaluation will be completed in future research work.

Once the case analyses were completed (cycle steps 1 -3) UML Use-cases were developed (cycle 4). The purpose of the use-cases was to document every specific step of each piece of the overall process. The base flow for the use-cases was developed from the original process model with alternative flows being influenced from the FMEA and FTA analyses. Once the use-cases were developed, the processes were analyzed for communication between groups, interactions between systems, and information used during the event. From this information analysis a list of vocabulary terms was developed (Table 17). These terms are abstractions and generalizations of the information types that were identified through the use-cases and are used in developing the classes and attributes within the UML Classification representing the product model.

Table 17: Product Model Development Vocabulary Terms

Reported Problem	Identified Hazards	Damages
Troubleshooting Source	Clinical Schedule	Services Affected
Complaint	Location of Complaint	Reporting Person
Dispatch Personnel	Response Protocol	Emergency Operation Plan
Expected Hazards	Extent of Damages	Source
Floor	Space	Room
Mechanical Zoning	Work Order	Shut-down Procedure
Mechanical Unit ID	Valve ID	Valve Location
Risk/Damage Level	Risk/Damage Incident Level	Occupancy
Space Use	Repair Estimate	Repair Schedule
Air Quality Testing	Contractor Repairs	Needed Work
Problem Location	Effected System	Available Supplies
Replacement Part #	Supplier	Problem Mitigation

Case Analysis Observations

As a result of the case analyses, observations were made about the link of facility management activities to healthcare activities and patient safety within healthcare. These include the time and efficiency of response. As the FMEAs were able to demonstrate, the longer the time it takes to mitigate and repair a problem, the more severe the level of damage (Lucas et.al., 2012). The more damage to the physical environment usually leads to enhanced risk and more hazards that threaten patient safety. It is important to efficiently and effectively respond to situations.

It was also noted that the type of response required depends on where the event happens within the facility. Responses are dynamic and no two cases can be treated exactly the same. Factors such as clinical services affected, time of day, occupancy by patients or proximity to patients, and extent of damage are all changing variables. Because of the dynamic nature of the response, it is necessary to make sure facility managers and personnel responding have quick access to all relevant information to minimize the impact of an event on clinical services. The changing variables need to be incorporated into the system in order to adequately supply the information to the response personnel to make sure the situation is handled correctly.

4.2. Product Model Development

The product model is developed as a UML Classification (Figure 13). The core of the classification is the `Event`, `Source`, and `Response` classes. The core classes hold operations for documenting and responding to any event. The `Event` class holds all the reporting data for an incident, including noticed symptoms, location of event, service affected, date, and time. The `Source` class holds operations to troubleshoot the situation and determine what component(s) is the source of the event. The `Response` class has two sub-classes, `Containment`, which deals with the initial response, and `Repair`, which holds operations and attributes associated with fixing any damages. Other areas of the classification include the Health Threats Definitions, Problem Type Definitions, Facility Documents, and Facility Information. The Health Threats Definitions, consisting of the `HealthThreats` class and its subclasses, and the Problem Type Definitions, consisting of the `Problem_Type` class and subclasses, are associated classes. When an event is recorded, either a health threat or a problem must be identified. With one object defined, the corresponding objects within the associated class can be determined. Facility Documents is where documents and forms related to the Building Control Systems are connected to the rest of the product model. `FacilityDocuments` is the main class and has sub-classes of `PurchaseOrder`, `Protocol`, `WorkOrder`, and `WaterIncursionReport`,. The Facility Information part of the classification is the `Facility` class and all its subclasses. The `Facility` class

holds all the information pertaining to the facility, its system, components, and documentation related to the components. The `Facility` class and its sub-classes are structured based on information available through the National Institute of Building Sciences, Whole Building Design Guide, Construction Operations Building Information Exchange (COBie) (East, 2012). COBie offers a standard that designers, contractors, and owners are becoming familiar with and will help ensure the facility information is captured in a structure way. Additional support classes are the `Hazards`, `Damage`, `ClinicalService`, `ClinicalContacts`, `Contacts`, and `Standards` classes. The `Hazards` class lists the hazards involved, such as saturated building materials, and the mitigation methods for each. `Damages` hold the physical components of the facility that will be involved in the repairs. `Clinical Services` holds the occupants of each space of the facility. `ClinicalContacts` is the class for holding clinical contacts that would be involved in different responses to situations. The `Contacts` class holds a subclass for `Contractors` and `Suppliers` and holds the contract information that would be involved in assigning and determining repairs. The `Standards` class holds relevant code regulations and requirements that are pertinent to conducting repairs.

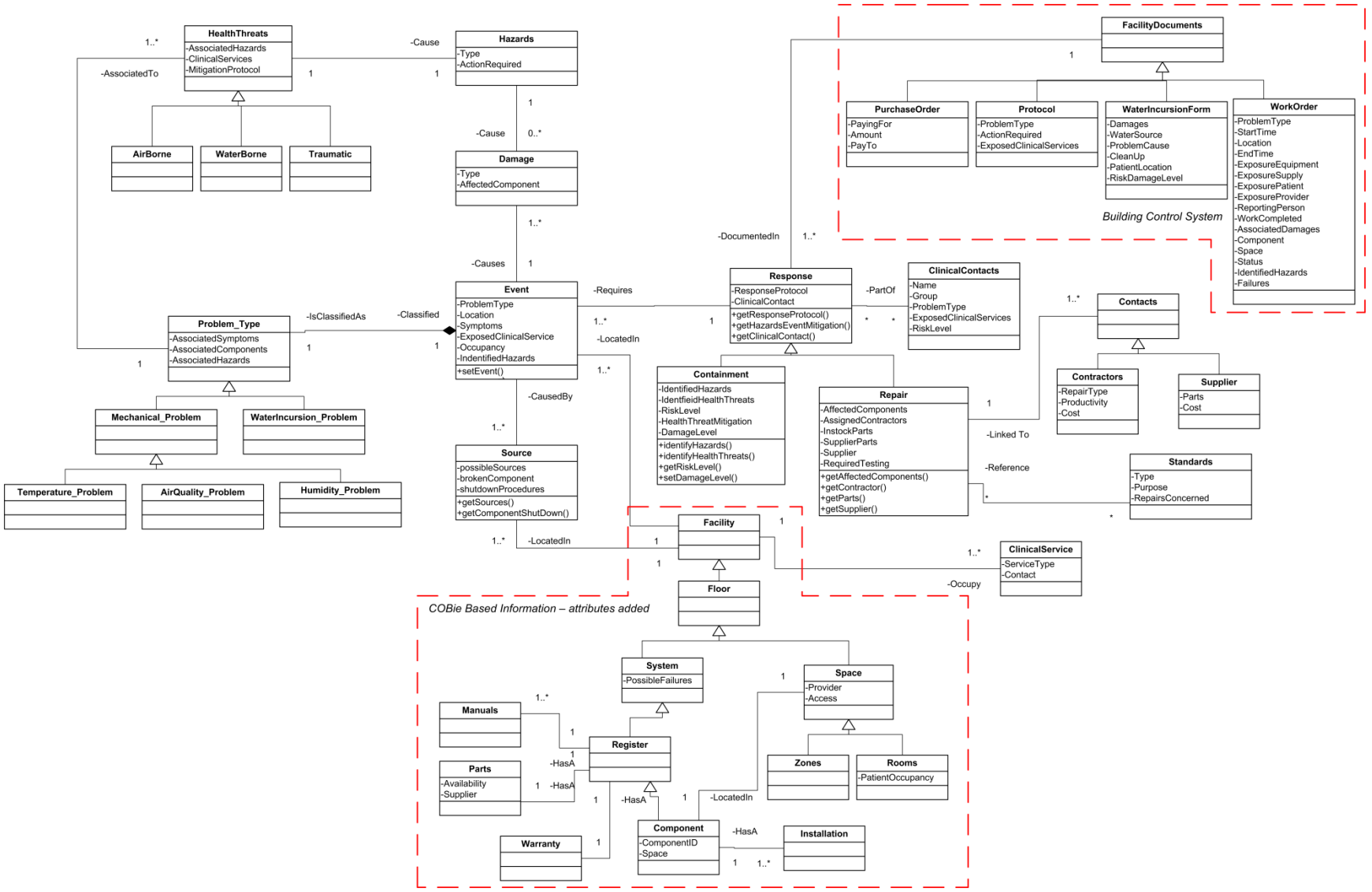

Figure 13: Product Model

Class Interactions

In order to explore the class interactions UML sequence diagrams were used. Sequence diagrams show interactions between objects and describe how groups of objects behave, or collaborate, with each other (Fowler, 2004). Object types are represented as rectangles at the top of each sequence diagram with a lifeline extending from the center of the rectangle. When the object is active, a box appears on the line. Messages, data transfers, and operations are represented as arrows between the activation boxes. Within the proposed product model, the `Event` class is the first object created within the product model when a facility event occurs. Documented as part of the `Event` object are attributes for symptoms, problem type, and location among other preliminary information. From these initial attributes the proper response and probable sources of the problem can be identified (Figure 14). In the example case study used for analysis, the problem type was a water incursion that had occurred within the operating room. This event would be documented as an `Event` object with the problem type as water incursion, location as operating suite #2, and symptoms listed as received from the nurse. By using the "ProblemType" and "Location" attributes of the `Event` object, the objective "getResponseProtocol" can be called within the `Response` class and retrieve the proper order of response for the situation. The response protocol would include any required actions. In the example case study, the problem needs to be immediately documented through the use of the Water Incursion Form which is part of the `FacilityDocumentation` class. Also as part of the response, any "IdentifiedHazards" from the `Event` object would need to be mitigated through the "mitigateEventHazards" objective within the `Response` class. In the example case, hazards of water dripping through the ceiling would need to be mitigated and contained to prevent additional damage. The source of the water would also need to be identified and shut down. The `Source` class uses the objective "getSources" which looks for a list of components within the `Facility` based on the documented location that would be possible sources for the documented problem type. In the example case, possible sources for water above an operating suite would include the chiller line of the air handler unit, a clogged condensate drain within an air handler unit, or a corroded cooling coil. To determine the actual "BrokenComponent" from the list of "PossibleSources", the possible sources would need to be checked manually to determine the actual cause of the problem. Once the cause is determined, the source of the water would need to be shut down. The shutdown information is available through the product model from the `Facility` class for the identified "BrokenComponent" , within the `Source` object as "ComponentShutdown".

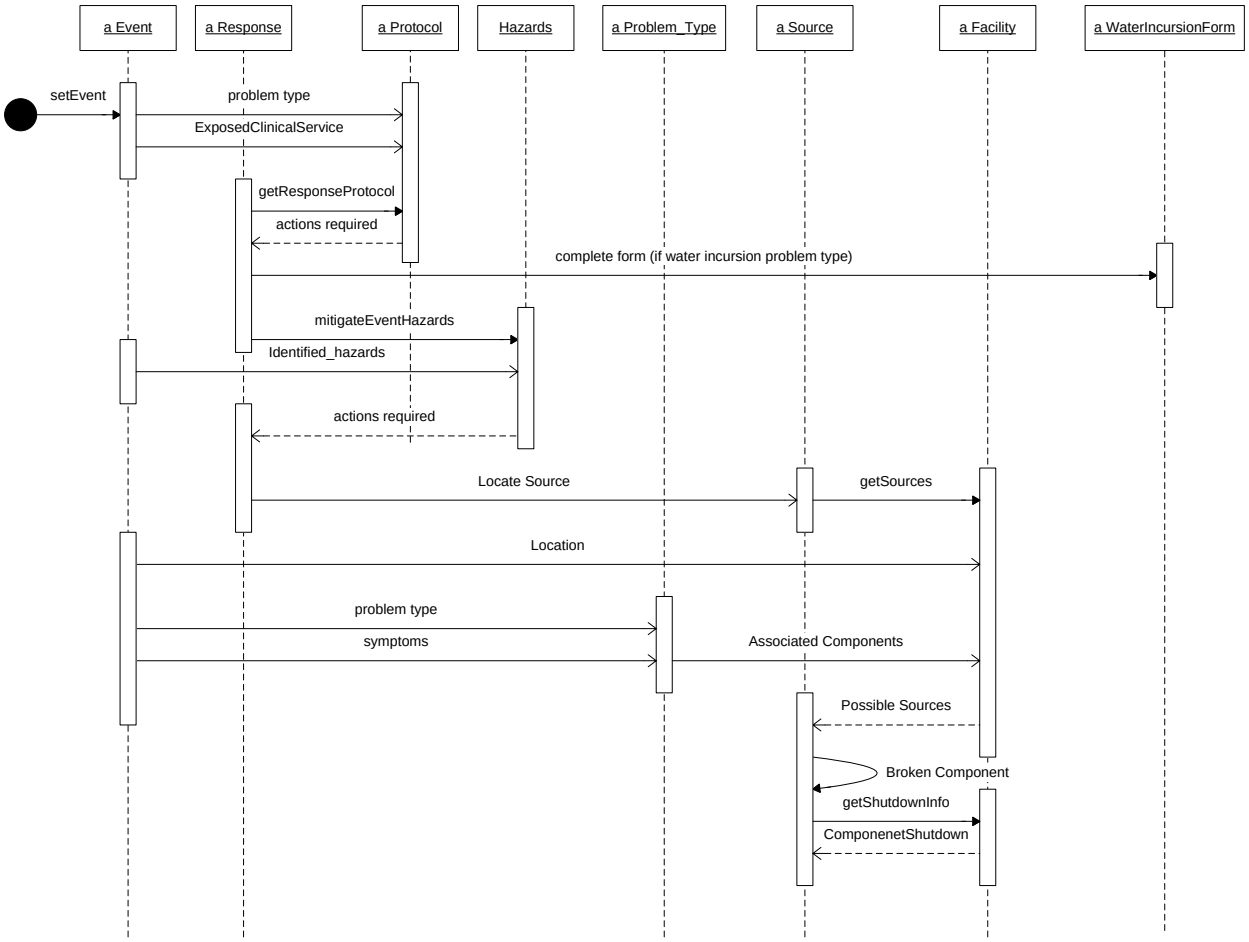

Figure 14: Sequence Diagram 1

Once the source is taken care of, the response protocol usually requires that certain personnel are notified to determine a specific plan of action (Figure 15). The clinical provider of the affected space and the type of problem are used to determine which personnel need to be contacted and what additional protocol needs to be followed. In the sample case, since it was a water incursion with water accumulating on the floor and water saturated walls within the operating suite, facility management personnel, the head nurse, head of surgery, hospital administration, patient safety coordinator, and the infection control coordinator are called to the scene. Who to contact is identified by figuring the risk and damage level of the incident. These are dependent on the problem type, location, and occupancy noted in the `Event` object.

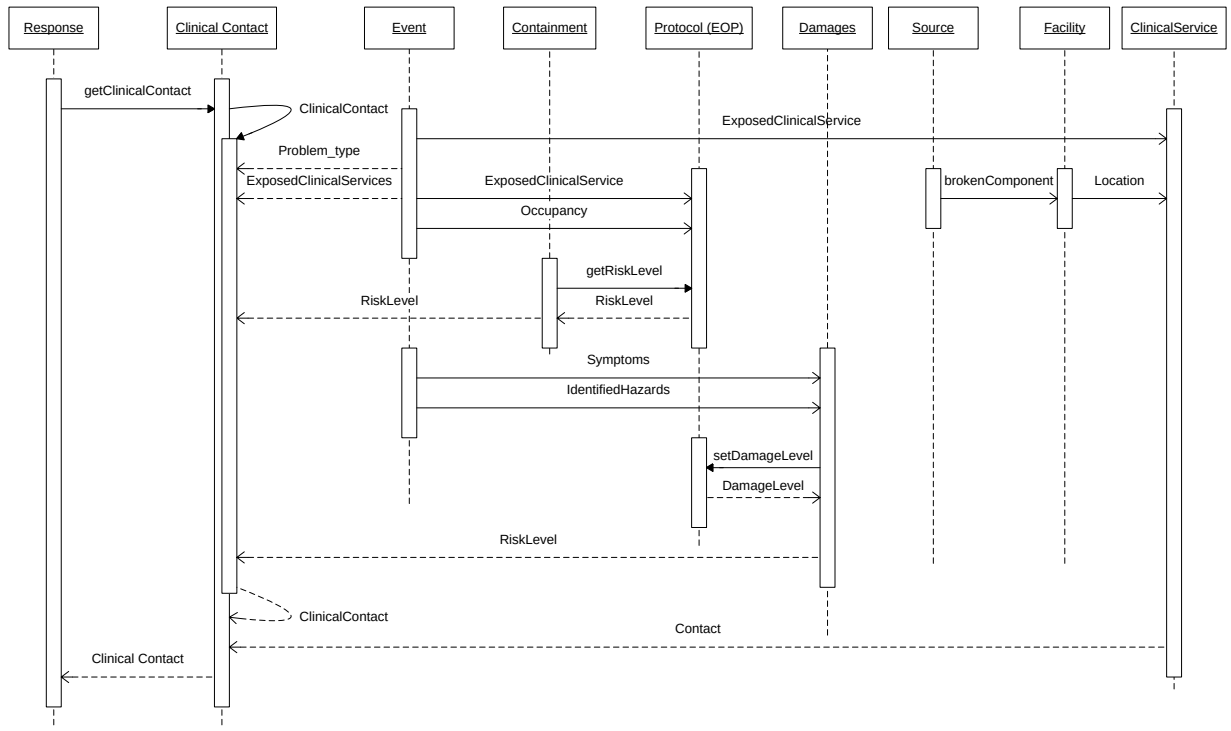

Figure 15: Sequence Diagram 2

During the response by the additional personnel the "IdentifyHazards" and "IdentifyHealthThreats" objectives are completed. To identify the hazards, the damages need to first be recorded as objects within the `Damages` class. Based on the location and symptoms with these damages a list of "AffectedComponents" can be retrieved from the `Facility` classes (Figure 16). The final damages are compiled by linking the "AffectedComponents" with the "BrokenComponent" from the `Source` class. With the "AffectedComponents" and the problem type, the hazards are able to be identified. These hazards may require additional containment and mitigation like in earlier in the process. In addition, any health threats need to be identified. This is done by taking the "IdentifiedHazards" and connecting them to the defined health threats within the `HealthThreats` class. In the case example, the "AffectComponents" include the damaged ceiling and walls from the water incursion. The hazards that were identified were the wet walls, water on the floors, a drop in temperature in the area once the air handler unit within the zone was shut down, and the wet ceiling within the Emergency Department below the Operating Suite. The identified hazards were then linked to potential health threats that the clinical staff would need to be aware of. To mitigate the threat, proper repairs of the damaged materials were completed but the clinical staff would have to be on the lookout for signs of the bacterial infections that

can be caused by moisture saturated materials. Fixing the materials within a short time period also helps to mitigate the health threats.

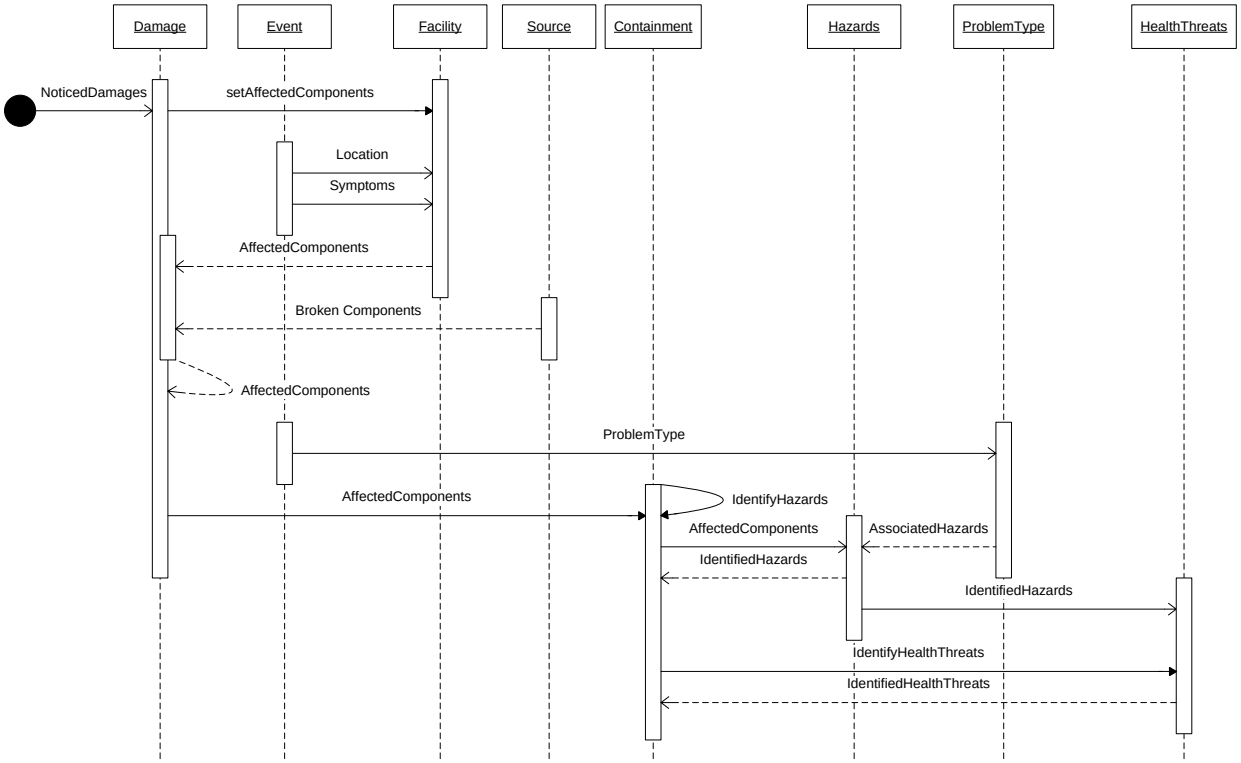

Figure 16: Sequence Diagram 3

The last part of the process is the repair of the damages. Operations within the `Repair` class take into account the "AffectedComponents" from the damages. They then check for replacement parts, either ones available in stock or from a supplier. The supplier of the parts is noted. Another operation is the assignment of a contractor. The type of work is compared to a contractor's capability and assigned. The `Standards` class is referred to and matched to the affected components to check for any testing requirements, such as air quality testing or moisture level checks of materials.

Classification Flexibility

The product model is designed to work bi-directionally. When an event is reported, either a problem type or a health threat needs to be included. The relationship between the `Problem_Type` class and that of the `HealthThreat` class allows for the alternative path as well. If the health threat was reported with the event instead of a problem type, the class interactions would be slightly different (Figure 17). The problem types that are associated with the health threat would first be filtered. For example, if the there is a string of related infections that are linked to an air-borne fungi noticed in a service area of the hospital,

the health threat connection would be linked to possible problems with the mechanical system. The source functions are similar to before by looking for possible mechanical systems that would be supplying air to the event location. From there, procedures would need to be completed such as looking for dust or testing filters for bacteria colonies. Once the source is identified, repairs would need to be made that may include cleaning the ductwork, replacing filters, and examining external air sources.

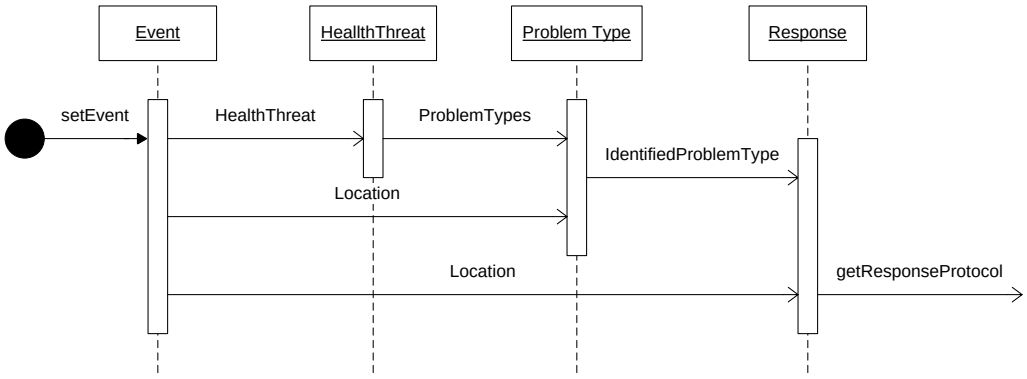

Figure 17: Alternate Class Interactions

Model Expandability

The product model was design to be abstract enough to be expandable in the future. It is not designed for one situation, instead the development of the classification's core allows for a normalization of processes and objectives. Facility information would change depending on the facility though the classification structure works for any facility. Additional subclasses in the `ProblemType` and `HealthThreats` classes can easily be added to account for more situations without modifying the product model's core or supporting classes.

4.3. Test Case Analysis

As a test case, information from a situation documented by Lutz, et.al. (2003) was used. In this case, a series of *Aspergillus* infections was identified in a cluster of surgical patients. Collection trays were used to determine the areas in which the patients were that the infectious spores were located. It was determined that the only place that the original 6 patients were located was within the operating suite. Since *Apergillus* is caused by air borne spores the air quality within the room was examined. There was an elevated level of spores than normal, so the air filters were replaced and checked for efficiency. Once it was determined that the air filters were not the cause and the levels were still elevated the system between the air filter and the operating rooms was examined. Through the use of cameras rust was found within some of the ductwork suggesting that moisture has been present within the system. The Variable

Airflow Volume (VAV) units located near the rust were dismantled and checked for moisture issues and *Aspergillus* spores. It was found that the insulation within the VAV units that was installed to limit noise had been damaged by water and was the source of the spores that caused the outbreak in the operating suite. As a response and mitigation for future events, all VAV's were examined within the hospital for water infiltration and removal of the insulation.

The data from this test case was used to test the developed product model. Due to the flexibility of the model, the health hazard is first identified. Because it is an airborne hazard, the problem type that can be identified is within the mechanical system. Air Quality had not yet included as a problem sub-class under `Mechanic_Problem`, so a `AirQuality_Problem` sub-class can easily be added to work with the test case as shown in Figure 18.

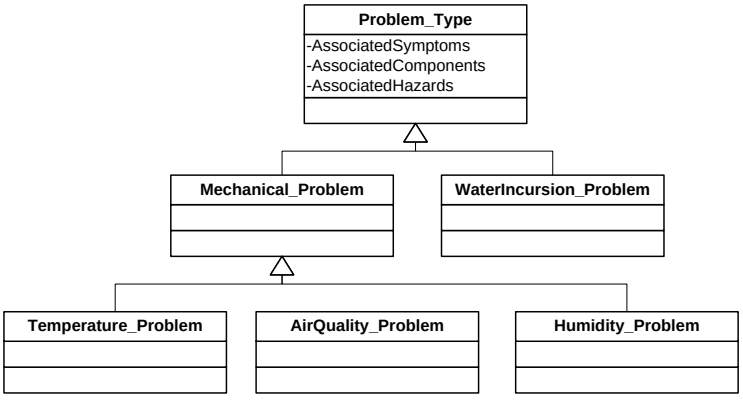

Figure 18: Modified `Problem_Type` class and sub-classes of UML Classification

The initial `Event` would be defined with the air quality problem type. The location of the event is defined as the operating suite based on examining the records of where the patients received treatment within the hospital. Possible sources can be determined within the `Sources` class and linking them to the `Facility` sub-class of `System`. Systems that are linked to an air quality issue are determined as the mechanical system. Components within this system that can cause the failure are identified as the filters, duct work, air handlers, and VAV units. The actions needed associated with the `ResponseProtocol` would include testing for air quality in the areas where the patients were located to make sure that the *Aspergillus* is not spread as part of the `HealthThreatMitagation` and `Containment`. It would also require determining within the mechanical system what was causing the health threats and the resulting hazard. This requires investigation by personnel and can include testing of duct surfaces, filters, and checking filtration rates and efficiency. Once the filters are determined to be clean from the infectious spores closer examination of the system was required until the damaged

insulation around the VAV was noticed. The system would then be repaired, with information documented in the `Repair` class attributes and operations. As part of the repair, appropriate testing would occur as required by the `Standards` class to make sure that the air quality is back to the necessary level. Lastly, as part of the response and containment other VAV's would be tested within the hospital to make sure it is not a recurring problem.

The flexibility of the classification system allows for cases that identify a health threat first to be incorporated into the product model to determine the source of the problem and conduct the proper response, containment, and repairs.

4.4. Conclusion

The challenges that exist for developing a product model for use within healthcare facility management is that there are variations as to how different organizations do their work. The product model is developed using case examples from one facility and how they would complete the work. Though the processes may be slightly different from facility to facility, the information needed to complete the processes is the same across the industry. The same standards and regulations are used in forming protocols. This allows a focus on developing the product model around the information allowing flexibility of actual process.

5. CONCEPTUAL MODEL FOR PROTOTYPE IMPLEMENTATION

Once the product model and ontology describing the information exchange mechanics was designed, a conceptual model for a prototype was developed to show the usefulness of the framework to support facility management activities. This chapter discusses the development steps used in designing the conceptual model, the Graphic User Interface (GUI) design, intended user interactions with the system, and how a test case analysis was completed to help verify the prototype's flexibility.

5.1. Introduction

Having a method for adequate capturing and storing information is only useful if that information can then be retrieved by the user in a method that can effectively support their work. To demonstrate the potential use of the product model and ontology that was developed as part of the framework a conceptual model of the prototype was developed. This conceptual model includes designed GUIs that users would use to actively work with the product model and ontology to retrieve information in response to a facility related event.

The purpose of the conceptual model is to demonstrate the usability of the developed framework as a mechanism for accessing relevant information during facility management response to patient safety events. The conceptual model uses Eclipse and Java to develop GUIs that allow the user to interact with the rest of the framework. The developed conceptual model remains within the scope of the currently developed framework with a demonstrated use to access mechanical related information during a patient safety event to support the users' response to the event. The main user of the prototype is intended to be facility management personnel, especially the maintenance mechanic who would be responsible for investigating the problem and organizing the initial response. The interactions of the facility management personnel within the prototype are demonstrated in the conceptual model.

The conceptual model is developed around the design case study "Case Study 1: Malfunctioning HVAC in Operating Room" that was used for development of the rest of the framework. As was the case in developing the product model and class interactions, scalability for inclusion of other systems that were not involved in the initial design use-cases is kept in mind. It is expandable for inclusion of additional building systems when the framework is expanded in future work. A test case was used to help ensure that the design of the concept model is flexible for situations beyond the design case study.

System Architecture

Figure 19 shows the overview of the system architecture for the prototype. The interactions between the different pieces of the prototype are designed within the conceptual model.

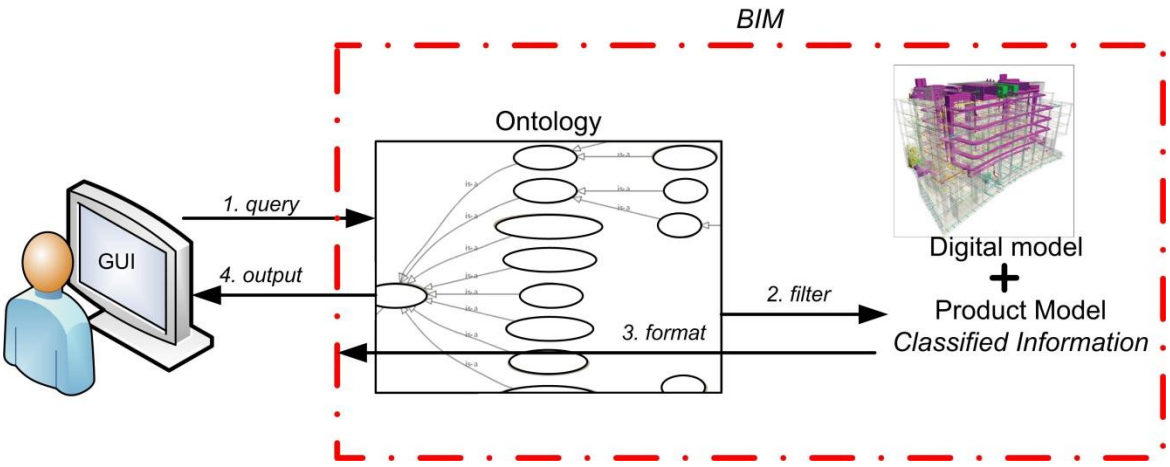

Figure 19: System Architecture Overview

Within the system architecture, the GUI allows for the user to define basic information needs and the framework generates the information the user needs. The developed product model serves as a container for storing information. Connected to that container is an ontology of information exchange mechanisms that allow for filtering, querying, and accessing different information based on the user input. The information exchange mechanisms define how classes interact with each other and are represented in the prototype as operations that run in the background coding. They also output requested information back to the user.

5.2. Conceptual Model Development

The conceptual model and prototype are designed around the intended use of supporting facility management response to safety events and intended user being facility management personnel. The development cycle for the conceptual model was as follows:

1. Use-case development: use-cases were developed to detail the interactions between the GUI, developed product model, and other systems. The use-cases helped to organize the operations performed by the system and ensure that the GUIs are being developed within the defined scope and intent.
2. GUI mapping: Using the use-cases as a basis, the seven main GUIs that are included within the conceptual model were mapped. This mapping identified the interactions between the GUIs and the product model. The interactions include background operations and information that is being input, exchanged, and output to the user through the GUI. The GUI mapping helps to organize the functions of the GUIs and define the programming that will be needed to obtain those functions.

3. Paper Prototyping: Paper prototyping was used as an efficient and effective method of sketching, organizing, and reviewing GUIs and their functions without the need for formal GUI development.
4. Conceptual Model: GUIs were developed within Eclipse. Functions were then mapped to the GUIs and diagrammed. Classes within the product model were connected to the GUIs to represent where the information would be retrieved from and how the information exchanges are handled.
5. Test-case analysis: The test-case analysis uses to additional case studies to test if the conceptual model design is flexible for use beyond the initial design case. Test-case information is mapped on the developed GUIs to check that all information needed in the additional cases could be handled by the designed conceptual model.

Use-case Development

The use-cases were developed in UML Format. UML is a visualization language that is used to model systems. It allows for specifying, visualizing, constructing, and documenting systems (Alhir, 1998). The Use-cases allow for documenting each individual step of the process. In the case of the design of the conceptual model, the different use-cases document the actions of the GUI with rest of the developed framework. The use-cases walk through the step by step interactions of the user with the GUI and the GUI with the product model. The information exchange mechanisms are represented as operations within the use-cases. Each use-case describes a different function of the prototype and became the base for the different GUIs. This allowed for organizing the GUIs so they incorporated the correct fields and features for the user to define specific aspects of the event and in return show the requested information through the GUI. The use-cases helped to ensure that the GUIs were not overcomplicated and only the necessary features to complete the task were included. The complete use-cases in UML format are included in Appendix L.

GUI Interaction Mapping

Once the use-cases were developed there was an understanding of the types of GUIs that were needed and the function of each GUI. In total seven main GUIs were developed from the use-cases. The GUIs were separated to show the different functions of the prototype. In order to organize the function of each GUI on paper and track the information exchanged a GUI Interaction Map was completed. This map is organized as a table with four columns (Figure 20 shows a partial table; complete table is available in Appendix M). The columns from left to right are *Work Order Documentation*, *Prototype GUI (User)*, *Background*, and *Product Model Store*. These columns represent where information is coming from, what operations are running, and how the GUI interacts with the product model and work order systems.

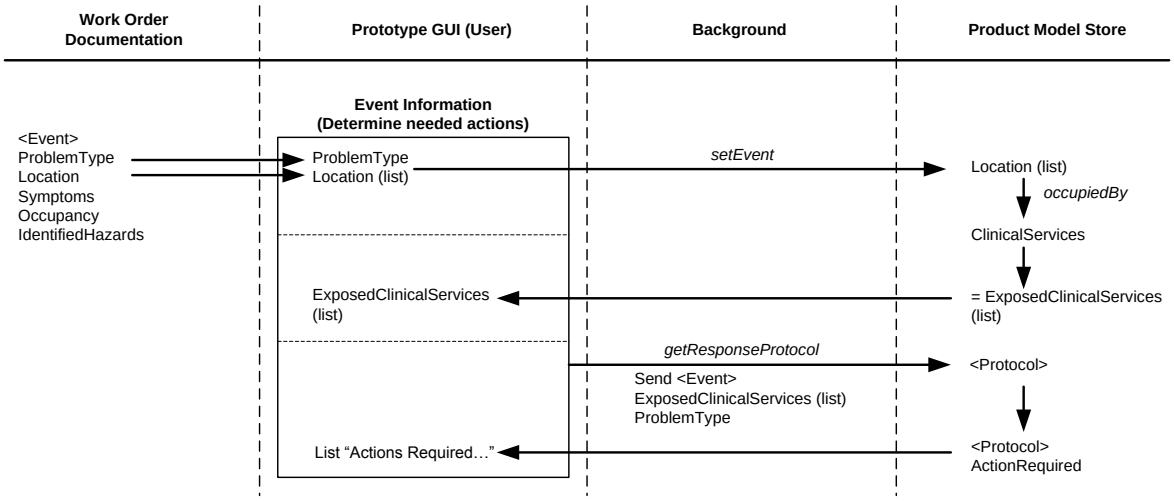

Figure 20: Partial GUI Interaction Table

Under the *Work Order Documentation* column is information that is originally reported and found within the work order that is associated with the event. If the framework is connected to the building operation system that contains the work order information, this information can automatically be input to the first GUI and stored within product model when it is needed. The *Prototype GUI (User)* column contains the separate GUIs within an outlined box under a title for each. In this case, the "Event Information" GUI is included. The operations of the system that are running within the background are represented under the *Background* column. Lastly, the *Product Model Store* column represents the information exchange mechanism that input, store, format, sort, and retrieve information from the product model.

The labels within the table represent the information classes and attributes of the product model where the information is stored or retrieved from. The bracketed labels represent the classes while the labels listed under them are the separate attributes. For example `<Event>` is the event class within the product model and "ProblemType", "Location", "Symptoms", "Occupancy", and "IdentifiedHazards" are attributes of that class.

The arrows represent information moving between the different systems. Operations are listed in italic along the arrow. Information that is involved in an operation is listed as an input from the GUI (such as "ProblemType" for the *setEvent* operation). If the information does not come from the GUI and is from the product model it is listed under the operation as can be seen in the *getResponsePrototcol* operation. If an attribute can hold a list of items it is listed to the right or directly below the attribute in parenthesis as scene with "ExposedClinicalServices (list)".

Within Figure 20, from the *Work Order Documentation*, the "ProblemType" and "Location(list)" information the <Event> class is input into the GUI. Using Case Study 1 as an example, this would be a water incursion event that occurred within the operating suite. The "Location" would consist of a list of spaces including the Operating Room, Sterile Supply, and Emergency Department Bays. This information is represented to the user within the GUI and used to start the event. The operation *setEvent* is run and within the background and product model the relationship of information is used to determine that <ClinicalServices> that occupy the affected spaces can determine the list of "ExposedClinicalServices" that is in turn output back to the GUI. The same GUI is also used to determine the proper response through the *getResponseProtocol* operation.

Each of the GUI's interactions and information exchanges were mapped using this format. The combination of the GUI Interaction Maps and Use-cases allowed for an understanding of the type of programming that would be required within the prototype and helped to lay out the conceptual model.

Paper Prototype

The GUIs were sketched on paper to lay out how each of them would take user input and then show the user outputs from the framework. The overall prototype layout is set up with the user input on the left and the display window shown on the right (Figure 21).

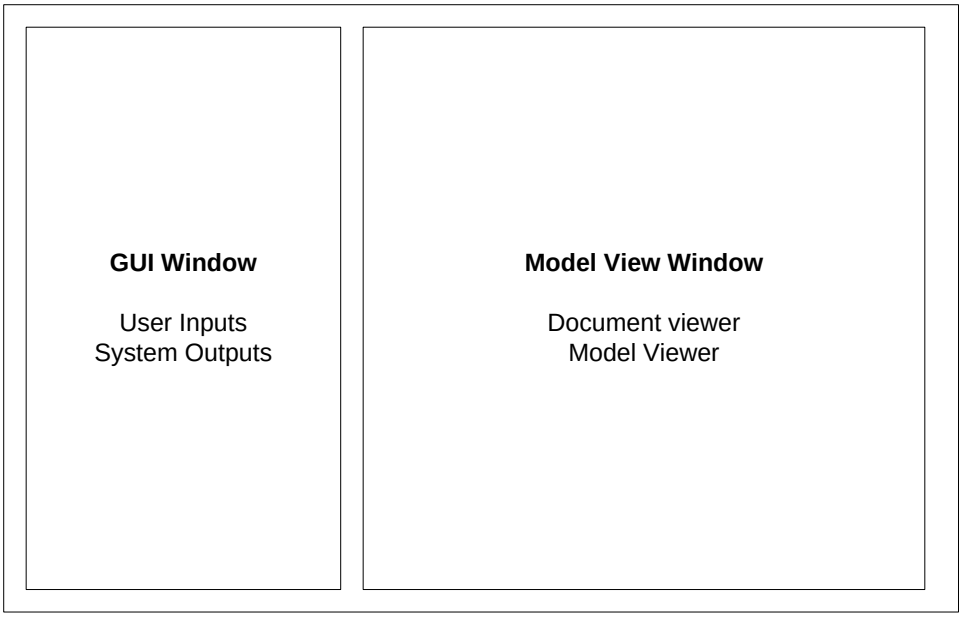

Figure 21: Prototype GUI Layout

On the left side of the prototype is where the main inputs and outputs from the system are located. The right side of the prototype is a display window that allows for the user to interact with the system and

information from the model is viewed. The GUI inputs and their functions for the left side of the prototype are summarized below:

1. Event Information: Classifies the type of event and determines the steps that are required based upon the problem type and location of the event.
2. Hazard Mitigation: Determine the mitigations that are needed for the associated hazards of the event that have been identified.
3. Locate Source: Based on the location and symptoms, the GUI and associated operations output possible sources that can cause the symptoms and are in the affected area. Linked to the possible sources is how to check and ensure each is working properly. The user can identify which of the sources is the problem and retrieve information on how to best shut down the affected system.
4. Identify Risk and Damage Levels: Based on the location and problem, the risk and damage levels can be determined using information that is available through the Emergency Operation Plan protocol. The GUI, using the needed information already input into the prototype automates the determining of the Risk and Damage Level. Also based on these variables a list of clinical and facility personnel can be listed that need to be involved in the response process. This GUI is linked to the database of contact information as well as knowing who is on duty under each contact category to allow for automatic paging of specified personnel.
5. Damages: This GUI takes the broken component that has caused the problem as well as the materials or parts that need to be replaced. It also allows the user to document the different damages that are noticed such as ceilings and walls that need replacing from water damage. The GUI lists the identified damages on the left of the prototype while allowing users to select the components from the model on the visualization side of the prototype. The damages listed help to identify hazards and health threats as well as what repairs are needed.
6. Hazards and Health Threats: Hazards that were identified during the initial documentation of the event as well as hazards noticed during the response process and those associated with the damages are input into this GUI. The hazards are processed for associated actions that are required to make sure they have all been mitigated or are under consideration for repair. The hazards, along with the location of the event, also help to determine health threats associated with the event and what the proper actions are to deal with them.

7. Repairs: This GUI takes the list of affected comments and helps the user to determine what work will be completed by in-house personnel and what work requires a contractor. When the repairs are divided, the replacement parts or materials needed for the in-house repairs are listed with a status of if they are in stock or need to be ordered. If the parts need ordering, supplier information is available through the framework. For contractor repairs, a list of qualified contractors for the type of work is available with contact information. The last part of this GUI is listing the types of testing that is associated with each the repairs to make sure that things like moisture levels and air quality are within the allowable standards.

Additional GUIs may be needed to support situations involving other facility systems that are currently outside of the scope of the developed framework. When the functions and layout of each GUI was determined on paper, it allowed for review and editing before it was formally developed within the conceptual model.

5.3. Conceptual Model Walk-through

Once the GUIs and basic interactions were designed on paper the conceptual model was developed. The conceptual model uses the designed GUIs and maps the inputs and outputs to the product model and ontology. The GUIs used in the conceptual model were developed using Eclipse and Java. These same interfaces can serve as the base for programming the prototype in future research. For the purpose of the conceptual model and demonstrating its potential use and functionality of the framework only the GUIs were needed at this time. The GUIs were then mapped to the product model and annotated as to how the information from the product model is exchanged and manipulated in determining the correct outputs back to the user.

The conceptual model is organized with a "Home Menu" on the main menu screen. As seen in Figure 22, the "Home Menu" consists of 7 different buttons that allow the user to access the different GUIs that perform different tasks throughout the response process. When the user selects one of the buttons, they would be taken to that GUI. For instance, when the "Event Information" button is selected, the user is taken to the "Event Information GUI" as seen in Figure 23. The right side of the prototype consists of a *Model View Window* that allows for interacting with the model and displaying information to the user.

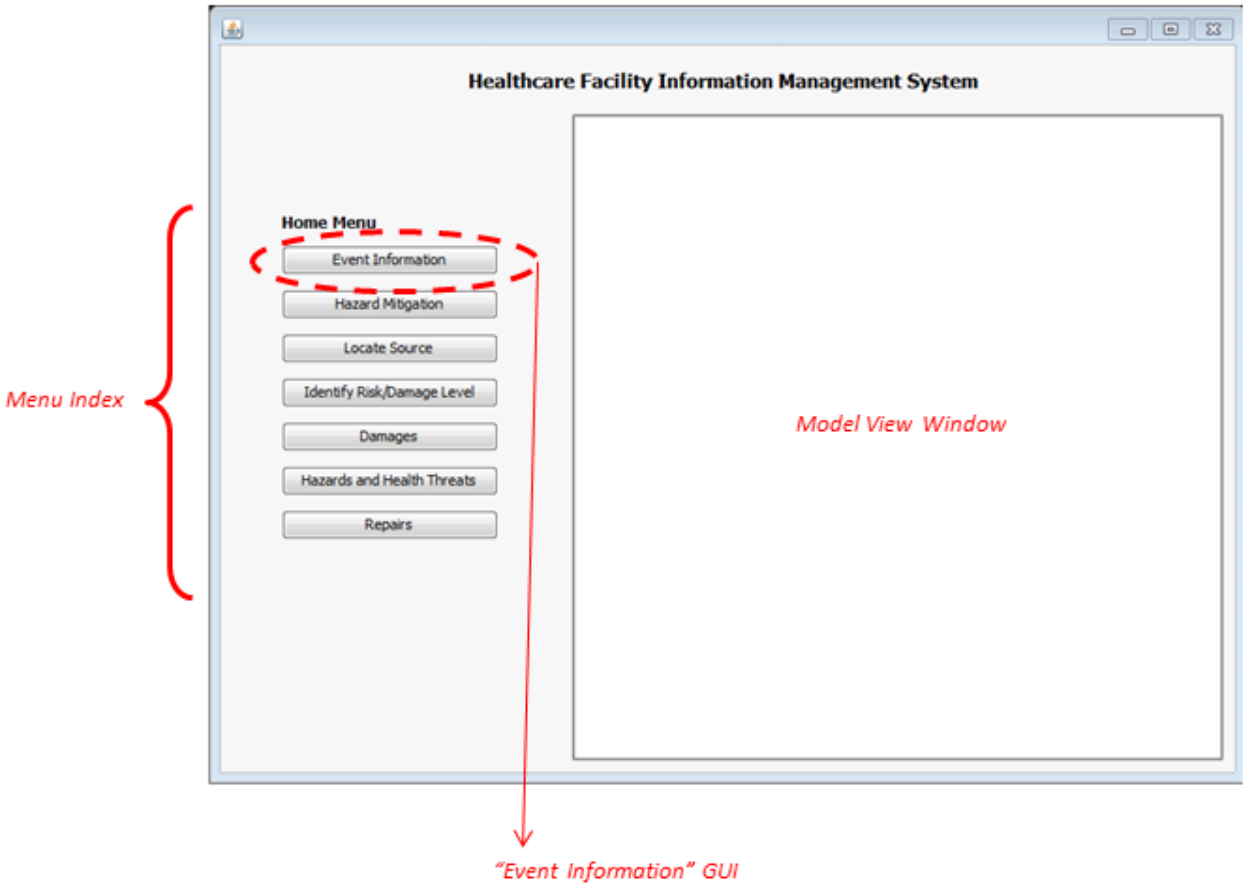

Figure 22: Home Menu GUI

The "Event Information GUI" (Figure 23) contains all of the information from the start of the event. Information for the "Problem Type", "Symptoms", and "Location(s)" is all available through the `Event` class within the product model. The `Event` class can be populated through the GUI or by information that is transferred by connecting the framework to the work order system that is used within the facility. If additional locations are discovered throughout the response process and event investigation additional locations can be added by the user through the "Add Location GUI" (Figure 24). The "Exposed Clinical Services" are determined by the relationship between the `ClinicalService` and `Facility` class that classifies what clinical services occupy which space within the facility. The areas listed within the `Location`(s) attribute of the `Event` class would be equivalent to instances of the `Space` sub-class. The `Locations` that were identified in the example case are "2012 – Operation Room 3", "2013 – Sterile Supply 1", and "1022 – Patient Room, ED". These locations are instances of the `Space` sub-class under the `Facility`. Each of the `Spaces` is occupied by a `ClinicalService`, "General Surgery",

"Central Supply", and "Emergency Department" respectively. These `ClinicalServices` become the list within the `ExposedClinicalService` attribute of the `Event` class.

The last area of the "Event Information" GUI is the "Immediate Actions Required". These are actions that the facility management personnel should take. They are based on the `Protocol` which is determined by using the `ProblemType` and `ExposedClinicalServices` to filter `ActionsRequired` which are the tasks to start the response process. In total when the "Water Incursion" problem type and listed exposed services are taken into account the response must include "Form Response Team", "Mitigate Hazards", "Diagnose Source", and "Shut-off Source".

The "Home Menu" button within the GUI will take the user back to the "Home Menu" GUI (Figure 22).

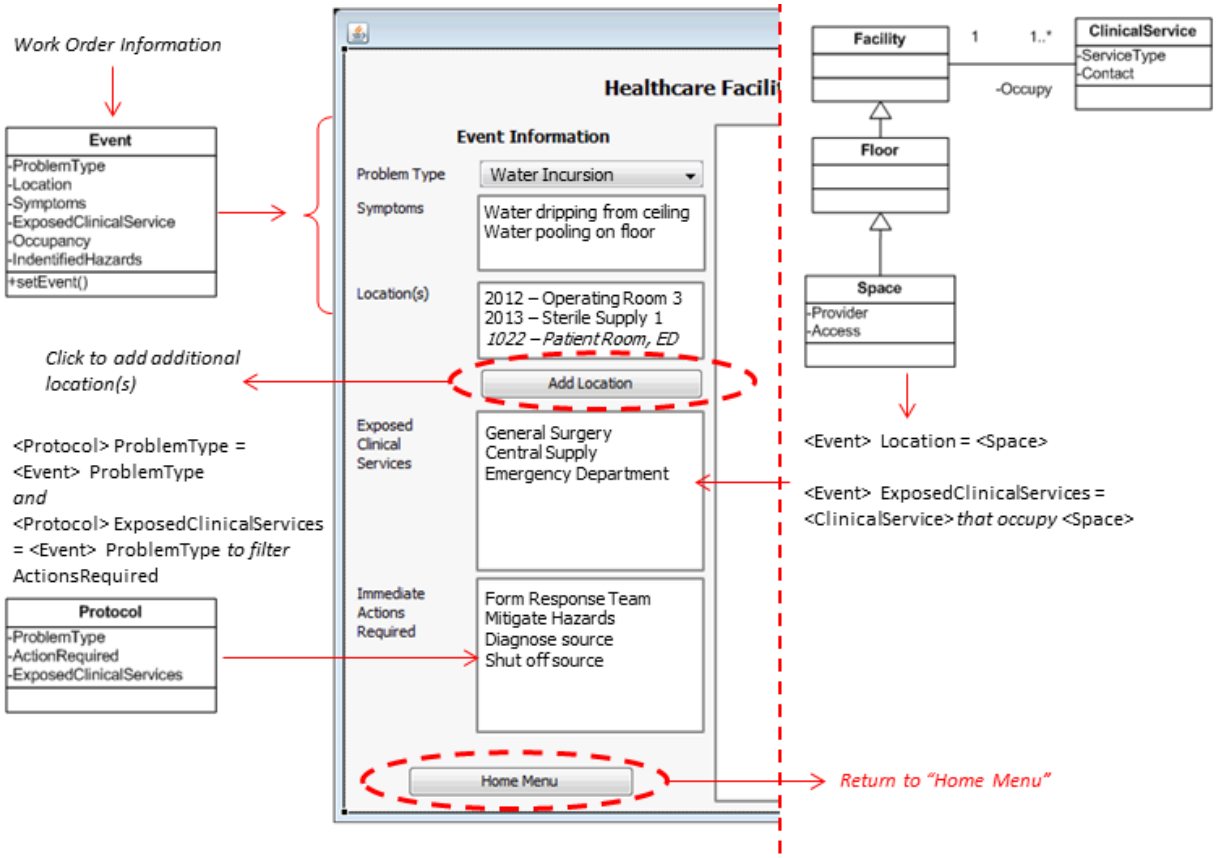

Figure 23: Event Information GUI

From the "Event Information" GUI the user is able to "Add Location" (Figure 24). This gives the user the ability to add locations that are involved in the event that may not have been immediately reported when the work order was created. Such as was the situation in the "Malfunctioning HVAC Unit in the OR" case where the initial report consisted of damage from water incursion within the operating room

and sterile supply. Once the investigation was underway it was also determined that water had leaked through the floor and damaged the ceiling and walls of an emergency department patient bay. The GUI accounts for adding locations. Within the *Model View Window* of the GUI, the user can select the proper building, floor, and zone and then highlight the affected rooms within the model. This action is then recorded back on the "Event Information" GUI (Figure 23) under the "Location(s)" and stored within the `Location` attribute of the `Event` class.

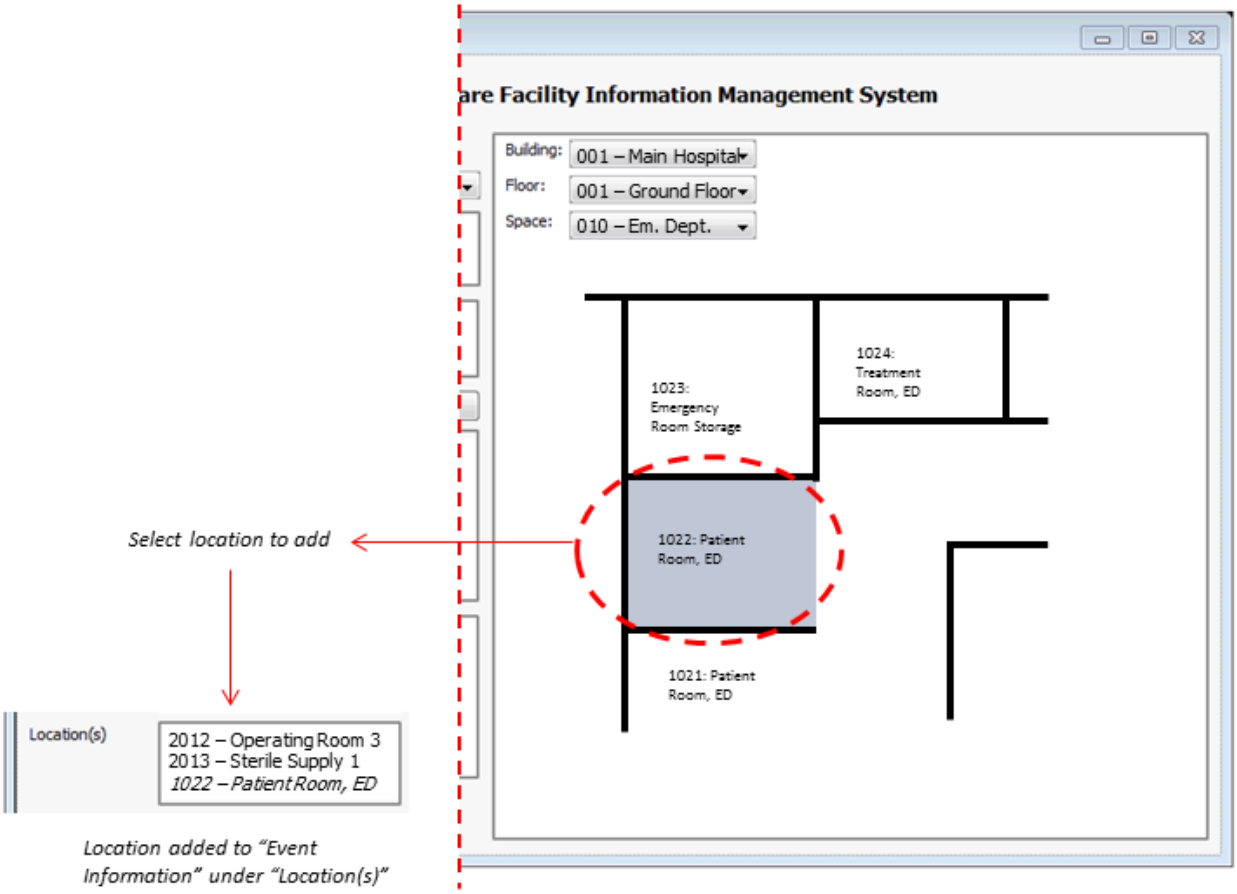

Figure 24: Add Location GUI

The next GUI the user would use is the "Hazard Mitigations" GUI (Figure 25). This GUI allows for a listing of the "Identified Hazards" which are written as *Location #: Category: Sub-Category*. For example the hazard "2013: Water: drip from ceiling" is an identified hazard in room 2013- Operating Room 3 and is a water incursion that has water dripping from ceiling. The identified hazards are stored within the `Event` class under the `IdentifiedHazards` attribute. Some hazards would be transferred from the Work Order System and identified in the initial event report while others would need to be added. The user can add hazards that are identified by clicking the "Add Hazard" button which would

then activate the "Add Hazard" GUI (Figure 26). In order to determine the "Actions Required" the `Type` of hazard is referenced to the `Hazard` class to filter out the `ActionRequired` to be listed on the GUI.

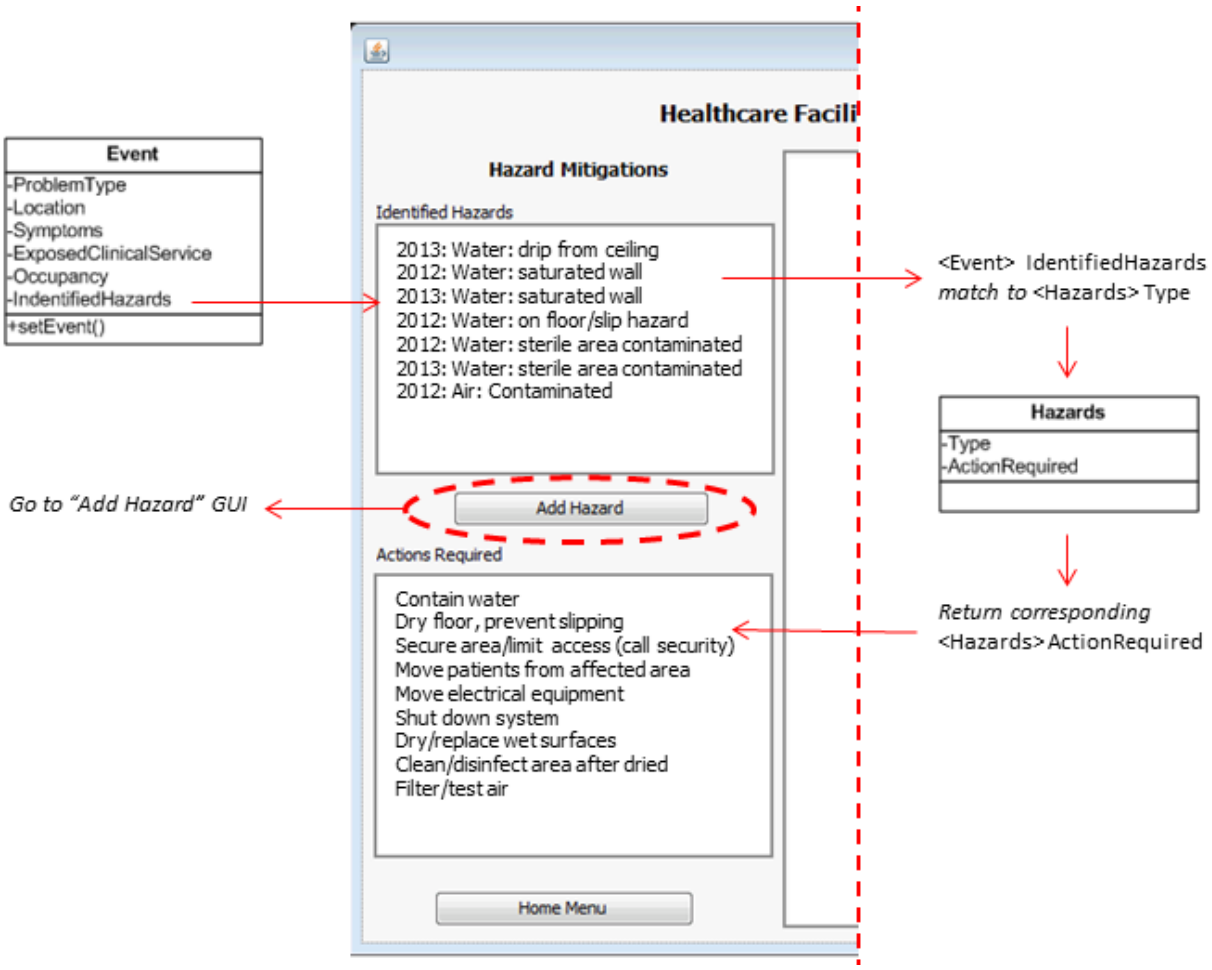

Figure 25: Hazard Mitigation GUI

When an additional hazard is located, the user can add that hazard through the "Add Hazard" GUI (Figure 26). This allows the user to identify the "Hazard Type" and "Hazard Sub-type" which would be instances of the `Hazards` class. It also requires the user to select the location. These locations available would be the ones that are already defined in the `Event` class.

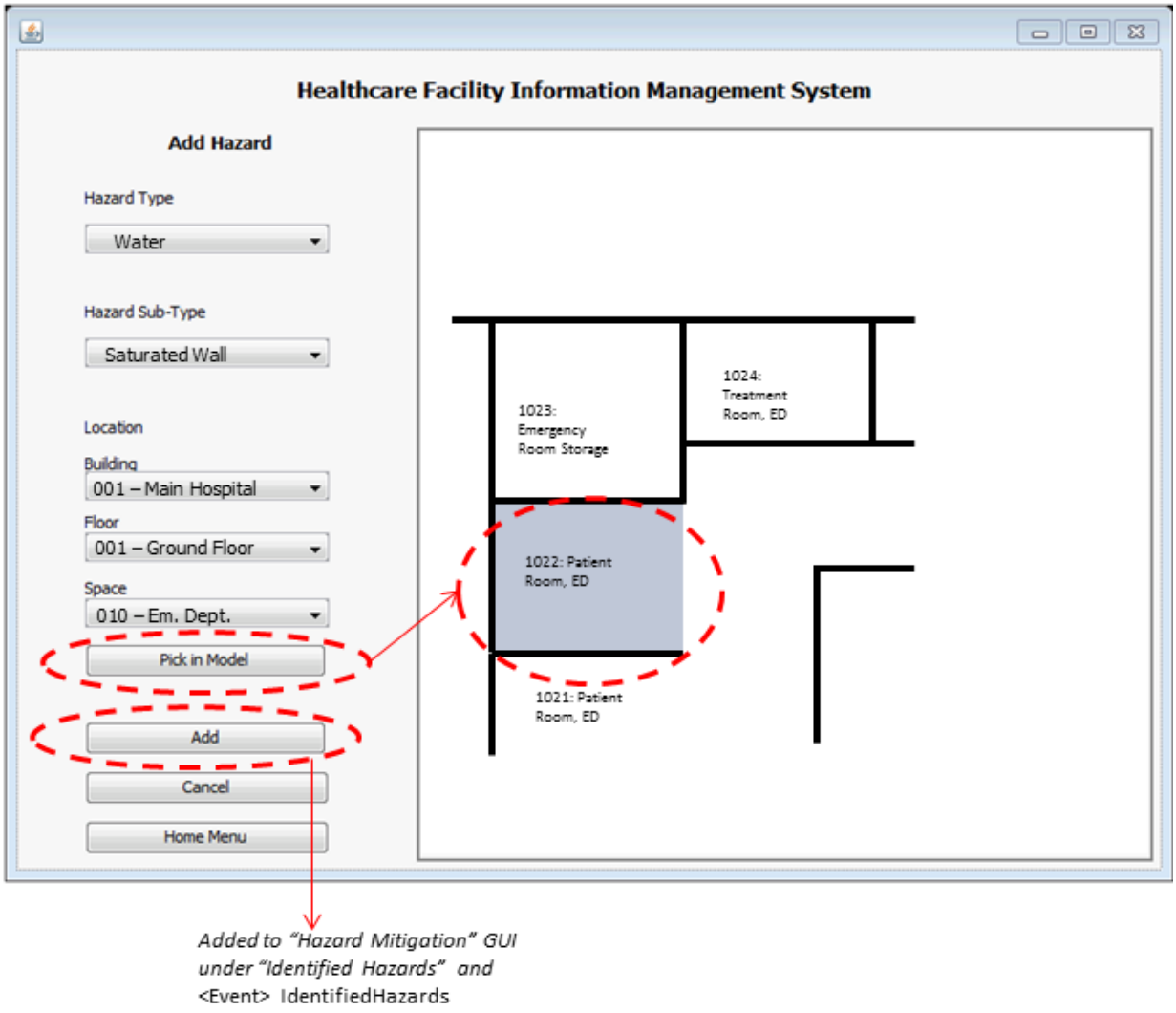

Figure 26: Add Hazard GUI

Another GUI involved in the immediate response to the event is the "Locate Source" GUI (Figure 27). This GUI takes into consideration the defined `Space` instances that are part of the `Location` of the `Event`. It then looks at instances of the `Component` class that are "locatedIn" the `Space` instances. This determines a list of components that are in the area of the problem. It then takes these instances of the `Component` class and looks for `PossibleFailures` that would match up to the `Symptoms` attribute of the `Event` class. In the example case, it looks at the "2012 – Sterile Supply 1" location to determine components of the facility that would cause "water from ceiling" as the `PossibleFailure` attribute. These components are then listed as `possibleSources` within the `Source` class and listed within the GUI under "Possible Sources". Facility personnel would need to look at each of the listed components and determine which one(s) of them is the actual problem. The GUI *Model View Window* is

used to help the facility personnel view location information and other operation information for each of the components when they are highlighted. Once the user determines the problem, they select it from the list and click "Identified Source". This is then stored in the `brokenComponent` attribute of the `Source` class. `shutdownProcedures` for the `brokenComponent` are then viewable in the *Model View Window* based on the `Manuals` class relationship to the instance of the `Component` class that was identified.

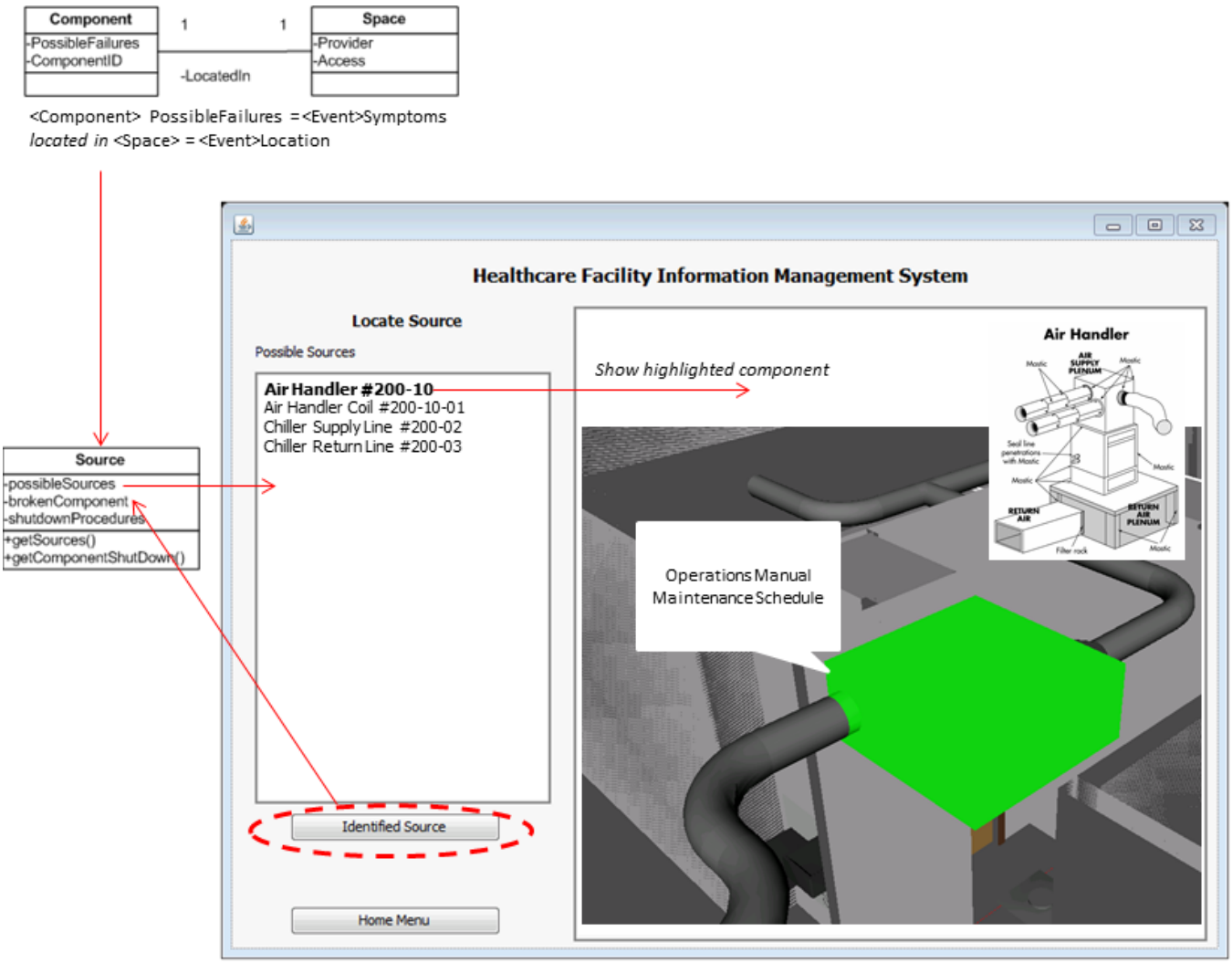

Figure 27: Locate Source GUI

Another GUI is the "Identify Risk/Damage Level" GUI (Figure 28) that is used to help determine the response team that needs to be formed to complete the mitigation and repairs. As a result of this GUI a Personnel Contacts list is developed of personnel who are needed to aid in the response. The "Event Infection Risk Level" and "Event Damage Level" are determined based on the `ProblemType`,

`Symptoms`, and `ExposedClinicalServices` attributes of the `Event` class. These are then compared to the tables within the "EOP" (Emergency Operations Plan) instance of the `Protocol` class. As a result, by using the water incursion problem type in the operating suite and emergency department, the "Event Information Risk Level" is classified as "High" while the "Event Damage Level" based on the degree of symptoms for a water incursion problem is defined as "Level IV". The "Event Information Risk Level" is stored as `RiskLevel` and the "Event Damage Level" is stored as the `DamageLevel` within the `Containment` class. These are used along with the `ExposedClinicalServices` to filter instances of the `ClinicalContacts` class to determine the personnel who need to be included under "Personnel Contacts". Once this list is created the user can manually add a contact and send a page to all personnel notifying them of the location and problem type.

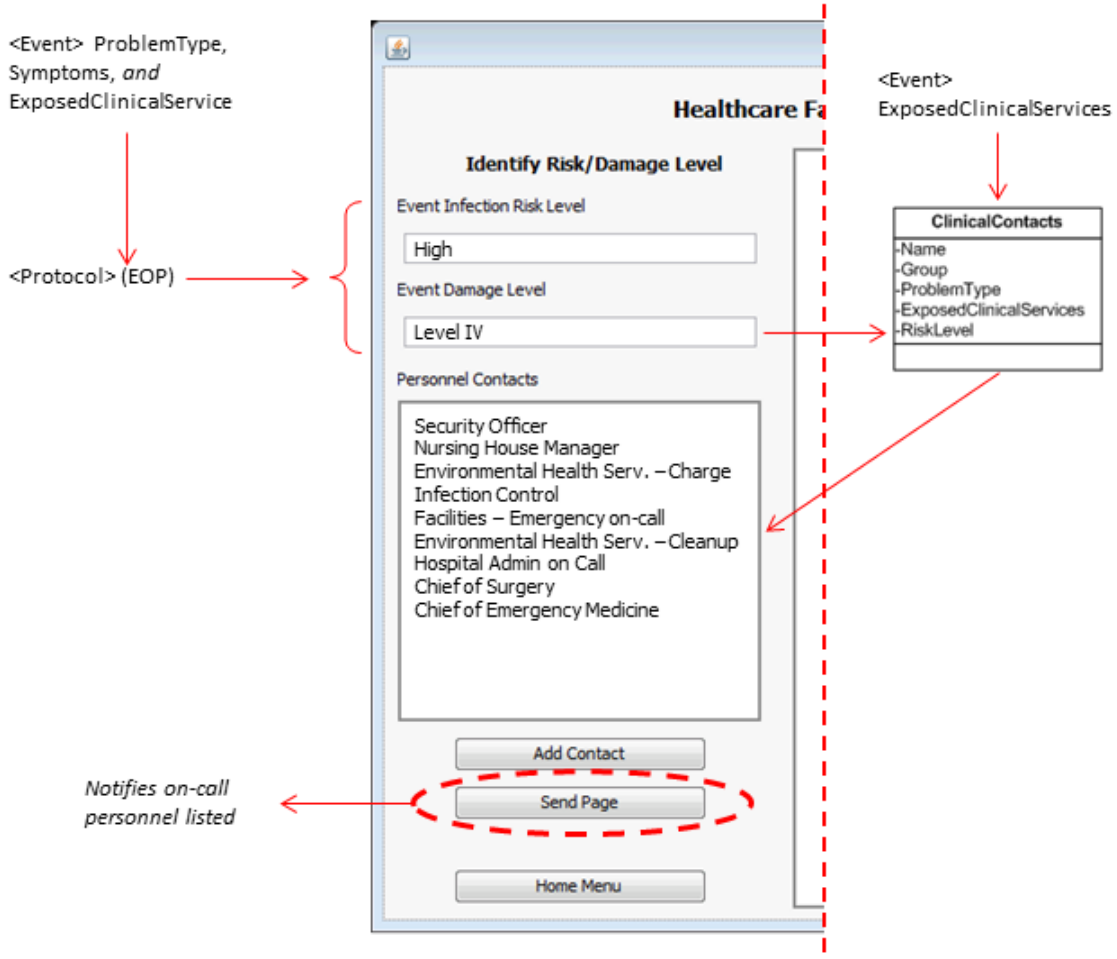

Figure 28: Identify Risk/Damage Level GUI

The “Damages” GUI (Figure 29) allows for listing all damages that were caused by the event that need to be repaired. The `brokenComponent` from the `Source` class is determined as the first damage. Additional damages can be added by the user by selecting the “Add Damages”. All damages are then stored as `AffectedComponents` within the `Repair` class.

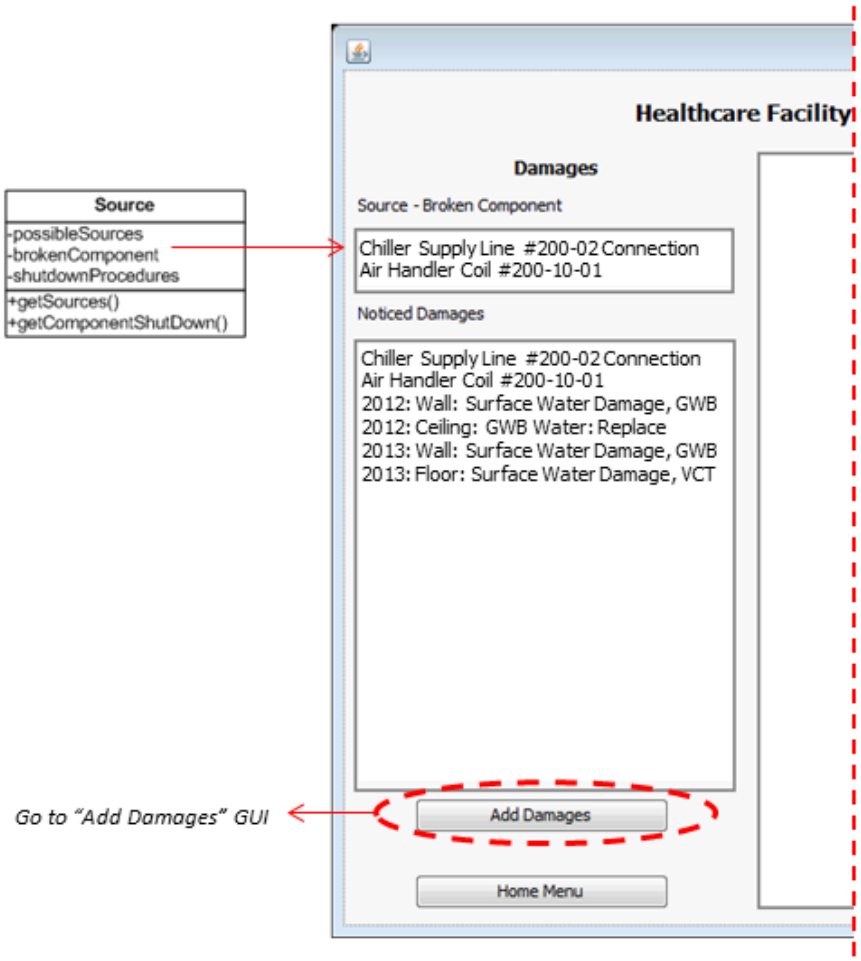

Figure 29: Damages GUI

The “Add Damages” GUI is used (Figure 30) to add additional damages to list of “Noticed Damages”. The user can define the location were the damages have occurred and then the type of damage based on the `Damage` class. The user can then select the component within the *Model View Window* to link the damage to the component. The damages are then added to the `AffectedComponents` within the `Repair` class.

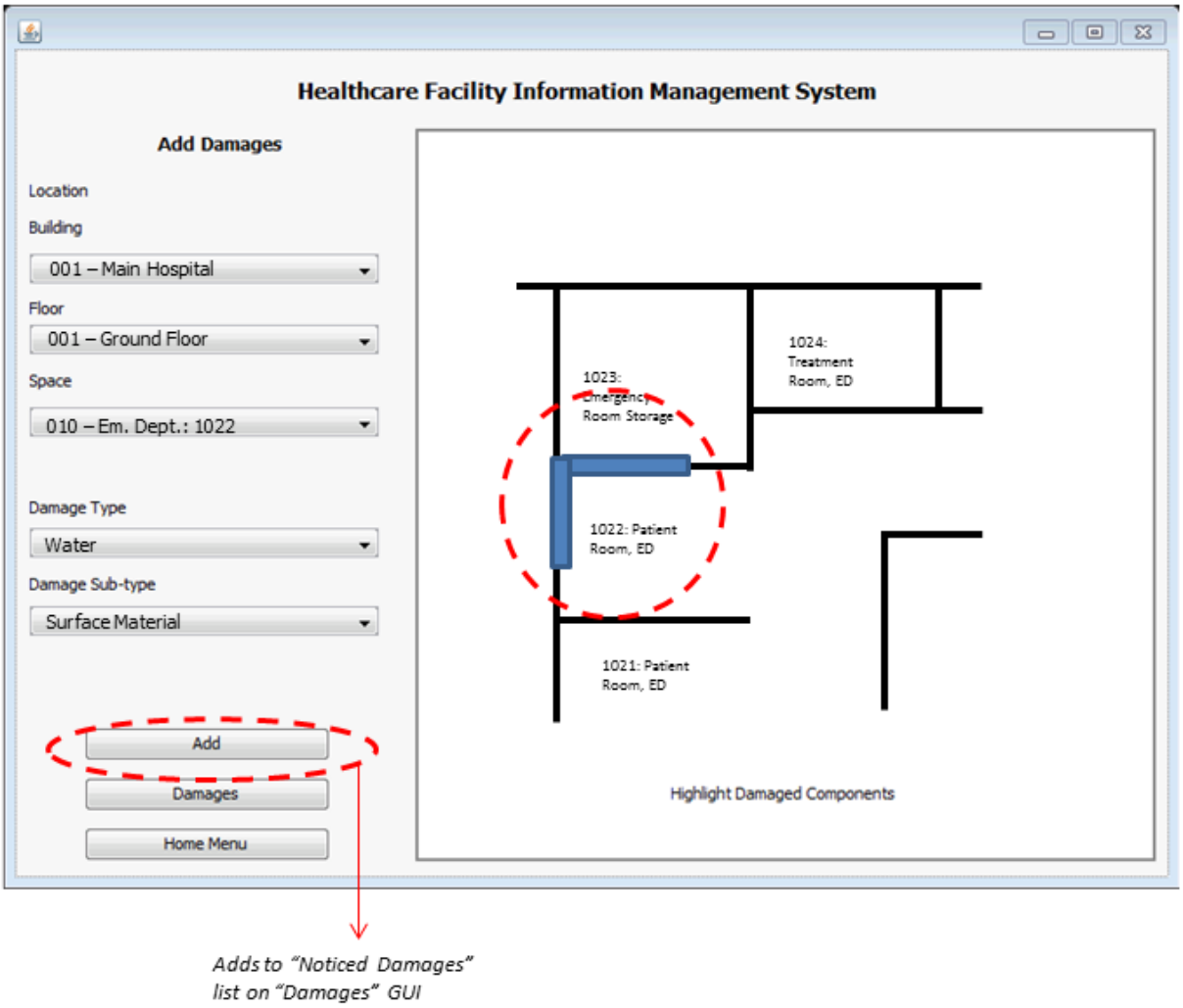

Figure 30: Add Damages GUI

Knowing the instances of the `Damage` class that are involved in the event will update the "Identified Hazards" lists and also determine the "Health Threats" in the "Hazards and Health Threats" GUI (Figure 31). Some instances of the `Damage` class are causes of instances of the `Hazards` class which causes the list of hazards, `IdentifiedHazards` in the `Event` class, to be updated. The `Hazards` can also cause health threats to patients and patient safety issues. This relationship between the `Hazards` and `HealthThreats` classes allows for determining the types of health threats that are involved in the event that administration need to be aware of and may take specific precautions to limit or mitigate. The health threats are also sometimes different depending on the clinical service within the area of the event. For that reason the `ClinicalServices` listed within the `ExposedClinicalService` of the `Event` class are also used to filter relevant health threats.

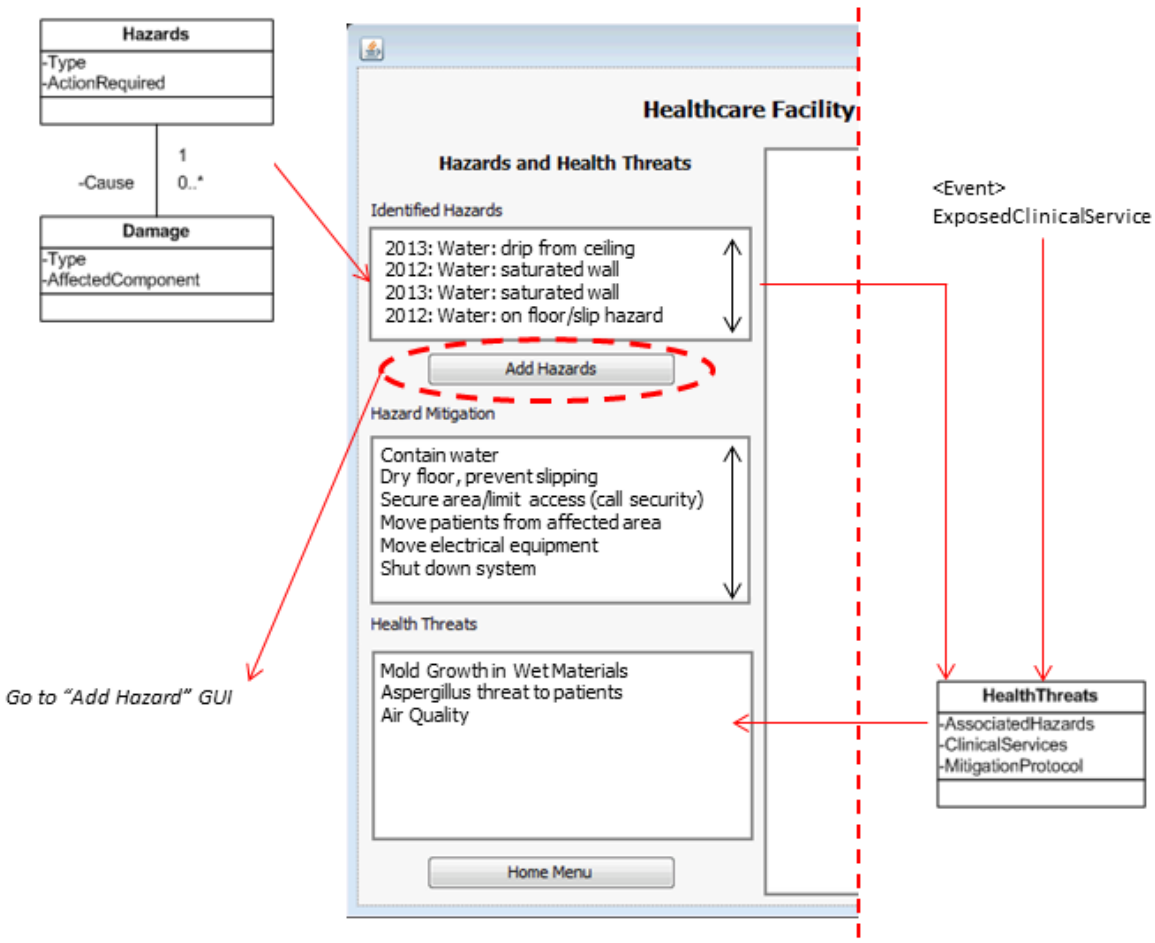

Figure 31: Hazards and Health Threats GUI

The last GUI developed within the concept model helps to organize the repairs that are needed. The "Repairs" GUI (Figure 32) allows the user to separate the repairs between contractor and in-house repairs. The "Repairs" are listed based on the damages that were determined and stored within the `AffectedComponents` attribute of the `Repair` class. The user is able to select which repairs would be "C", contractor repairs, or "I", in-house repairs. From here the user can select to view either set of repairs by selecting the "In-house Repairs" button to activate the "In-House Repairs" GUI (Figure 33) or the "Contractor Repairs" button to activate the "Contractor Repairs" GUI (Figure 34).

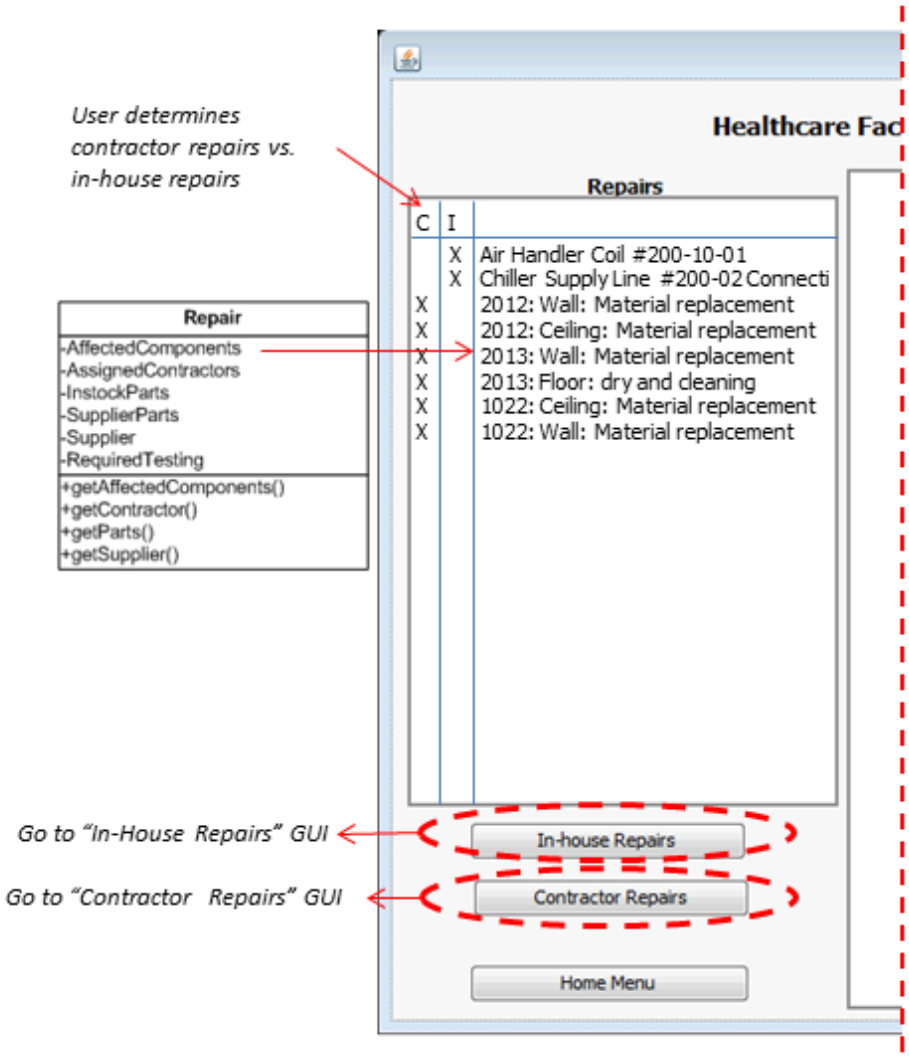

Figure 32: Repairs GUI

The "In-house Repairs" GUI (Figure 33) uses the *Model Viewer Window* and lists the repairs by part along the bottom of the screen. The parts are noted if they are in-stock along with a room number. If the part is not in stock then a supplier is listed. Clicking on the supplier gives the user the contact and order information or would allow them to find an alternate supplier. Clicking on the part would show the part and related information within the upper part of the *Model Viewer Window*. This information can then be used to make the repairs.

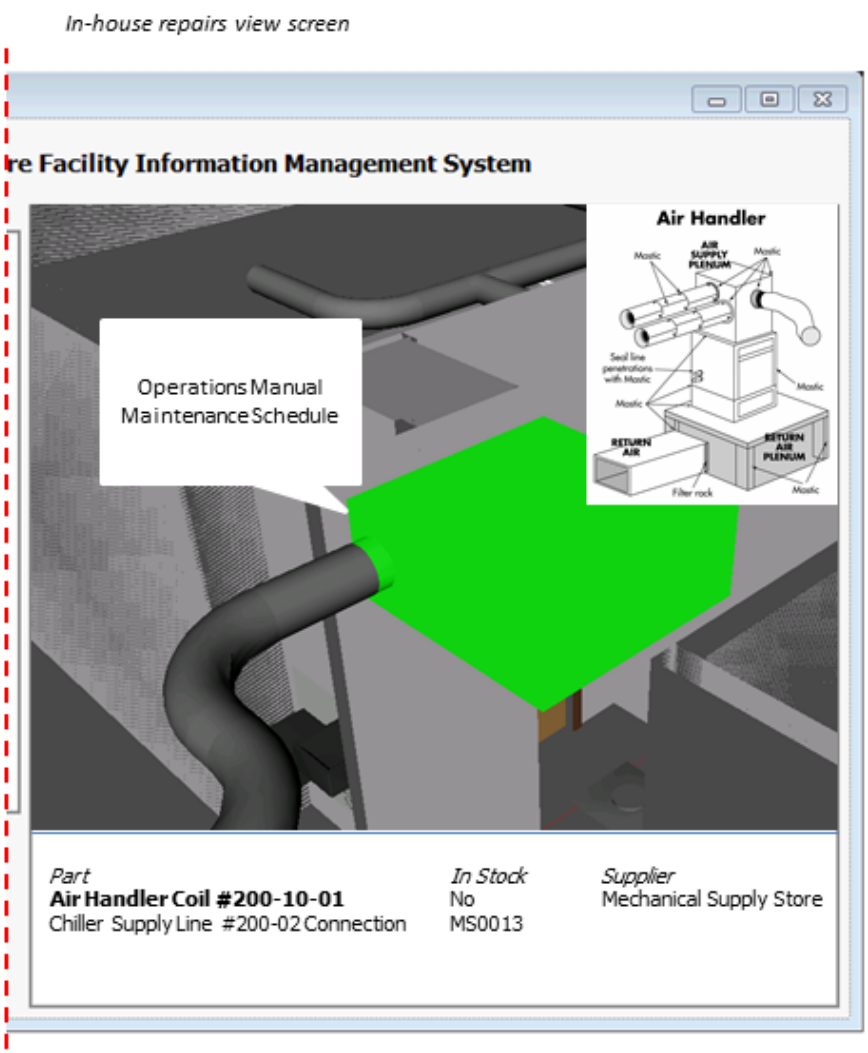

Figure 33: In-House Repairs GUI

The "Contractor Repairs" GUI (Figure 34) lists the different areas of work that need to be repairs. Along with each repair is a contractor that is able to do that type of work with contact information. The type of repairs and contractors are sortable. The GUI helps to organize the start of the repairs that need to be completed.

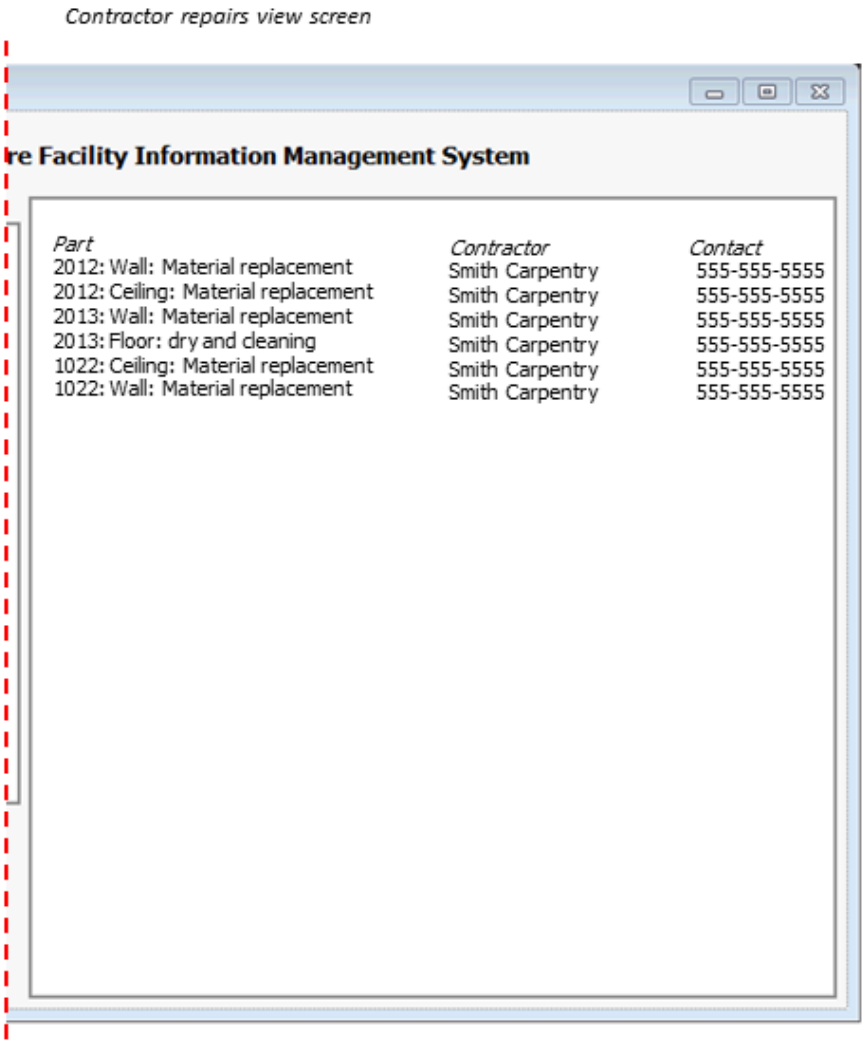

Figure 34: Contractor Repairs GUI

5.4. Conceptual Model Test Case Analysis

Once the conceptual model was designed around the "Malfunctioning HVAC in Operating Room" design case study, test cases were used to analyze the conceptual model for flexibility in incorporating other facility related patient safety events.

The first test case was the case study entitled "Chiller Pipe Burst/Air Conditioning Shutdown" that was described in Chapter 3. The information from this case was overlaid into the developed GUIs to check to make sure all needed information would be available. The "Event Information" holds the problem type of temperature with symptoms being too hot in the patient rooms. "Exposed Clinical Service" and "Immediate Actions Required" are determined as they were in the conceptual model walk-through. The

"Hazard Mitigation" GUI serves the same function as the walk-through and allows for identifying hazards and mitigation methods needed.

The area where there is a slight difference is locating the source. Within the case study, the actual cause of the temperature raising is a chiller line burst in the basement from the main chiller supply line. Within the GUI, possible sources are determined by looking at components in the affected area that will cause the problem. It would be feasible to recognize that the chiller liner temperature and pressure is below what it should be in the area where the problem was originally detected, but the ultimate cause would need to be backtracked. These causes are identified within the fault tree analysis that was completed and discussed in Chapter 3. The larger system of where the component is located would need to be examined. This system to component relationship is already defined within the product model. It would just need to be linked within the "Locate Source" GUI that is developed within the conceptual model. This would need to be handled by adding an optional button. Instead of the "Identified Source" button that was in the initial conceptual model design, a "Search Root Cause" button was added (Figure 35). This takes the selected possible source and gives information about the system that it is a part of, in this example one of the options would appear as "Main Chiller Line". From here the model would work the same as previously described and allow the user to continue the process by identifying the infection risk and damage levels, documenting damages, identifying health threats, and organizing repairs.

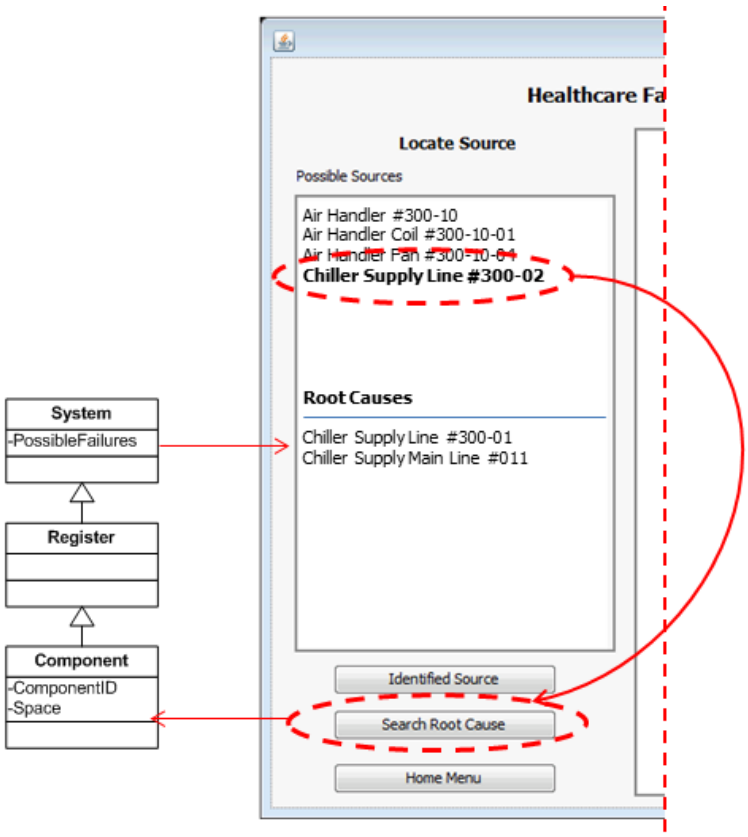

Figure 35: Locate Source – Modified GUI

A second test case that was examined within the conceptual model is documented in Mohammadpour (et.al., 2012) and consists of a blockage in a main sewer line for a hospital. In this case, disposable anti-bacterial wipes and other materials that were not intended to be flushable were flushed into the system by environmental services personnel. The materials created a blockage in the main sewer line that exited the building. The situation was noticed by healthcare personnel when grey water started to accumulate along a floor drain on the ground floor of the hospital between central sterile and food services. Immediately food service and central sterile had to stop using their equipment that drained water into the line while facility management personnel worked at locating the source of the problem for fear that the sewer would back up into those locations. The blockage was found at the outside of the building between the lobby and the campus sewer main. Traditional drain snakes and augers that facility management personnel had on hand were not enough to remove the clog. Contractors were called in to help set up containment areas where the sewer line was located within the ground floor of the hospital. Pieces of a concrete wall needed to be removed to access the blockage and use a hydro-powered auger to clear the debris.

For this test case, the conceptual model revisions for the previous test case would be used. Within the response, the conceptual model allows for inclusion of problem type and location. This would give a list of protocol that needed to be followed. The hazards and mitigations would be accessible within the `Hazards` class. To locate the source, the "Search Root Causes" feature that was added would be used to access information for the system of the identified source at the problem location. The initial drain in that location and the pipes it was connected to was not the root cause. The root cause was a blockage near the sewer main. The damages, hazards and health threats, and repairs would all be organized as designed within the original conceptual model.

5.5. Discussion and Conclusion

The conceptual model developed was designed with the intent that for future research a prototype would be implemented. That prototype would include the designed GUIs and interactions as described within the conceptual model. In order to work better with a fully developed BIM, the framework would need to be able to work within a modeling application. Some options include Bentley's Microstation that offers API's for user development and works well with customized overlays or an open source and open BIM application such as BIM Server. The ideal platform for the prototype will be an open model that is compatible with the Industry Foundation Classes (IFC) standard for information exchange and interoperability (buildingSmart, 2012). The goal is for the prototype to overlay a platform to allow for the connecting of facility and clinical information.

6. CONCLUSIONS AND FUTURE RESEACH WORK

Currently within the AEC industry information exchange through the facility lifecycle is fragmented and the facility management phase of the lifecycle remains the most disconnected from the rest. Poor information exchange and communication have been documented as the main causes for this disconnect (Goedert and Meadati, 2008). Fragmented and disconnected information lead to wasted time and inefficiencies (Deng et.al., 2001; Eastman et.al., 2008; Gallaher et.al., 2004).

Another information exchange and communication disconnect also exists during specific phases of the facility lifecycle between different entities within the facility. This can be represented within the healthcare industry between clinical staff and facility management. Facility managers are required to keep complex healthcare systems operation without causing disruptions to clinical operations. The physical condition of the building has been linked to patient safety and well-being (Ulrich et.al., 2004) so efficient facility management operation is important.

The identified research problem is that there is a information exchange and communication disconnect between phases throughout the facility lifecycle and between groups within phases of the lifecycle. The operations and maintenance phase of the facility's lifecycle is disconnected from the rest while poor information exchange exists between facility managers and clinical operations. In response to this identified problem, this research aimed to create a framework to create a method for a more efficient and effective method of managing healthcare facility information.

A BIM-based framework was used to help organize lifecycle information to support facility management activities and promote needed information exchange between clinical operations and facility management. The designed framework takes into account both clinical and facility management information that is needed for facility managers to respond to events within healthcare. Their quick and effective response can help save money and reduce health threats to patient safety.

This chapter summarizes the links that were identified between facility management information and clinical information through case study analysis methods. It also summarizes the characterizations of information that influences the development of the healthcare facility information management product model, the product model and ontology development, and how the use of the conceptual model allowed for demonstrating the potential use of the framework. A list of contributions and benefits of the conducted research is also included with identified weaknesses and how they can be overcome through future research work.

6.1. Healthcare Facility Information Management Framework

The healthcare facility information management framework aims at giving facility managers a more effective and efficient method of managing facility information. In doing so, case analysis methods were used to define links between facility management information and clinical information within healthcare. This allowed for identifying and then characterizing types of information that are involved in the response processes to patient safety events. The two cases studies used were "Case Study 1: Malfunctioning HVAC Unit in Operating Room" and "Case Study 2: Chiller Pipe Burst/Air Conditioning Shut Down". Both involved malfunctioning mechanical systems within the clinical operations environments that required facility management personnel to react in a timely manner, determine what was happening to cause the problem, and determine the correct method of response. The cases were documented as process models and then a FMEA was completed to draw connections between the severity of the event to threat to patient safety and clinical operations. The FTAs were completed to help map potential root causes to different types of failures within the examined system. These allowed for determining an extended data pool to use when developing the use-cases that were eventually analyzed for information needs to influence the product model and ontology development.

The information links that were identified between facility management and clinical operations showed that the problem type and clinical service area (or location of event) were the major variables in the level of response that was needed for any event. These two types of information allowed for determining the proper protocol for response. The location and clinical service are linked as certain clinical services occupy specific locations or spaces within the facility. So if the location was determined, it allowed for easily computing what clinical services are affected for any one event. The problem type and location also allows for easily determining the type of hazards and health threats that would be associated with the events by drawing relationships between them. In this matter, the main information that is needed for any event is the problem type (or at least symptoms of the problem), the location, and clinical service.

The problem type, location, and clinical services affected became the core of the product model. By knowing the clinical service that occupies a location and the problem type other information can be determined. This includes the type of protocol that is required for a particular event, the immediate responses to hazards that are associated with a problem, personnel required for response, health threats to look out for, and mitigations needed to prevent excess damage and risk.

Specific to facility management response and minimizing damages, the product model can determine, based on the problem type and location, what system and component may be causing the problem. This allows information for checking the components and shutting down the systems to be quickly relayed to

the user. The responding facility personnel can immediately go into action to find the problem component and shut down the related system and make sure that all hazards are accounted for.

Enhancing the response would be the frameworks link to other existing systems. For instance, the information for location, problem type, and symptoms would be included within a work order entry. By relaying the work order number, this information can be automatically populated within the prototype and framework. This would reduce the amount of information that needs to be manually input and removes the duplication of inputting information reducing the possibility for human error during the input process.

6.2. Contribution and Benefits

Contribution

The major contribution of this work is a product model and ontology framework that takes both clinical and building information related to facility management events and structures it for efficient use. The product model and ontology framework address the issued identified within the problem statement of fragmented information horizontally throughout the facility lifecycle and vertically between concurrent processes within the operation and maintenance phase. The framework links relevant clinical information and facility information with possible event types to assist facility managers in their efficient response. This was completed by tracking and mapping the information that is needed to support facility management processes and identifying information links between facility management information and clinical information. The tracking and mapping of the information allows for the information to be captured and stored within the designed product model throughout the lifecycle of the facility to support downstream processes, specifically those pertaining to facility management activities. By identifying the links between facility information and clinical information, information exchange mechanisms were included within the design framework to ensure that appropriate clinical information is readily available when needed. The product model and ontology serve as the core information storage and exchange mechanisms for the overall proposed healthcare facility information management framework.

As part of this contribution, the following were completed and necessary for the product model and ontology development:

- Tracking and mapping of information needs throughout the lifecycle to support FM processes
- Identifying information links between facility management information clinical information.

Tracking and Mapping of Information Needs to Support FM Processes

The first task in designing the product model and ontology and supporting this contribution is the tracking and mapping of information needs to their origins and needed format to more effectively support FM

processes. This allows for information capture throughout the lifecycle of a facility to support downstream processes, specifically the information to support FM activities involving the maintenance and repair of mechanical systems in healthcare facilities. Using the developed product model and ontology to capture and store information throughout the facility's lifecycle in the identified format allows for improving information exchange and ensuring that information is readily available during the FM operations and maintenance stage.

Identifying Information Links between Facility Management Information and Clinical Information

Another part of the contribution of this research is identifying the information links between facility management information and clinical information. The linking of clinical activities and information to the operation and maintenance of the facility and facility management information allows for an understanding of the variables that determine the response to an event. This helps to characterize the information that is important to the event response and the formation of the product model and ontology. This understanding also leads to the identifying of information exchange mechanisms that exist and those that need to be improved which can lead to a benefit of improved communication and increased efficiency in work.

Benefits

Benefits of this work include:

- A potential to increase efficiency in work
    - Connect to existing building information systems and streamline operations
    - Offer quicker response to patient safety events, minimizing health threats, damages, and cost
    - Potential for revised workflows to offer more efficient and effective processes
- Provides framework for intelligent information management system for healthcare facility information
    - Improved communication of information through the facility's lifecycle
    - Improved information exchange mechanisms between facility and clinical groups

Increased efficiency in Work

A significant benefit of the work is an increase in efficiency. The work is attempting to use a BIM-based framework to normalize the existing system of completing FM processes. It captures information and then manages that information based on how FM processes are currently handled. With its connection to the existing building control systems, it allows for a quick and seamless retrieval and filtering of information. The improved management of information should allow for quicker information access and

reduced time spent sorting through information by FM personnel. During mechanical related events, prolonging repairs can often add to the potential risk to patient and staff safety and health as well as add to the physical damage to the building. Improving the management of information and increasing the efficiency to which it can be retrieved can help minimize damage and costs of any particular event. The improved management of information of the framework can allow for personnel to do more work in the same amount of time and resources by improving information access and improving the efficiency to which they are able to complete any particular activity.

Revised workflow to more efficient processes is another potential benefit of the research. By understanding the processes that were mapped, redundancy can be removed. Information only needs to be entered into one system if the relevant systems are connected. The management of the information will only need to take place in one area. Removing the redundancies will improve the quality and efficiency of information management. Examples of a revised process would be a reduced number of steps needed in a process, thus making it more efficient. This includes a reduction of calls to find information in plans and specifications, looking up previously completed work orders, etc. since the mechanic will have access to this information through the framework.

Framework for Intelligent Healthcare Facility Information Management System

Another benefit of this work is that the framework lays the groundwork for an intelligent information management system for healthcare facility information. This framework can lead to improvements of information management through the facility's lifecycle as well as information exchange between clinical and facility management groups. Through the basis of the groundwork put in place within this research there is a potential for an organizational system to help streamline FM tasks and support decisions with quick access to information in times of crisis or for regular maintenance.

6.3. Future Research Work

In completing the current objectives there are several research tracks that can be extended from this work. These include expansions to the framework to include other systems and healthcare organizations, validation of system with industry personnel, usability studies to help in technology adoption and GUI design, pilot study implementations, and adoption into existing facilities.

Expansion of Framework

Before the framework can be piloted effectively, other systems need to be examined to be included. There also needs to be an examination of other healthcare facility practices. Planned events and regular maintenance would also be incorporated into the framework. This is required because the current

developed framework only examined unplanned mechanical related events while consulting one healthcare organization.

Even though the framework was designed with the intent to add other system information, information used in responding to events involving other systems such electrical, plumbing, pneumatic tubes, etc. need to mapped against the product model and ontology. This mapping would ensure that all relevant information for responding to these types of events can be managed by the framework. If the information does not currently have a place holder within the framework, then it would need modification for inclusion of the additional information types.

Examination of typical processes in other healthcare systems is also needed. The assumption for this research was that policies regulated processes enough within the healthcare industry to make the information needed to solve one type of problem that may occur similar throughout the industry. By documenting the typical response of other healthcare organizations in process models, similar to those that were developed for the original case studies, it would allow for identifying differences between systems and help to determine if the processes are actually normalized through the industry or if certain flexibility of user interface would be needed for each facility. The information to solve the problem would be the same no matter which facility, so this should minimize the effect on the product model, however if a process is different enough, new information exchange mechanisms and methods for interacting with the product model may be needed. A study other healthcare organizations responses to events would help determine how much of the framework is able to be normalized for use across the industry or if processes can be modified to make them normalized.

Incorporating planned events and regular maintenance into the framework it would allow for a more completed healthcare facility information management system. This can be done in two ways, by building in the processes to the current framework and product model or by creating a secondary sub-model that connects to the facility information portion of the product model and uses a totally new ontology to support the information exchange. Either way, the GUI interactions would need to be different as the processes to support planned events are different than those that support unplanned events.

System Validation and Usability Studies

Though the response processes that were incorporated into the concept model for the prototype were validated by the industry there needs to be overall information validation and usability studies completed of the user interfaces. The system validation will examine the responses and information output from the system and make sure that is correct to industry standards. The usability studies would make sure that the

actual users of the technology would be able to work with the developed interfaces. Some of the things that would be looked at during these studies include:

- Accuracy of system response to situation
- Output information accuracy
- Ease or difficulty for the user to understand the GUI
- Ability of the user to work with GUI
- Ease of learning the system by the user
- Ability of the user to retrieve the information they are looking for
- Best organization method of presenting information to the user

The goal would be to make sure the GUI interactions are efficient and effective and do not add to the work load or overcomplicate implementing a new technology into a complex environment. The usability studies would help to improve the adaptability of the technology into the industry. This study would be done as an iterative design process with a minimum of three iterations to redesign and improve the GUI. By doing the usability studies and making necessary changes it would also validate the prototype and framework as an efficient and effective method for managing healthcare facility information.

During the usability study, user acceptance would be gauged. This would be completed through a series of semi-structured interviews and subjective questionnaires with the group of potential users. The point of the interviews would be to document the acceptance of the technology and better judge the potential benefit of the technology. The information gathered would help to determine if the use or design of the system needs to be reexamined or if a pilot study to gauge actual acceptance and measure true benefit of the system would be worthwhile.

Pilot Study Implementations

A pilot study would help measure actual acceptance and measure the true benefit of the system. The pilot study would involve finding a healthcare organization that sees a potential benefit for adopting the technology. The pilot study would look for:

- Acceptance by workers of technology
- Track length of adoption, to where the workers are comfortable using the technology
- Examine actual use of technology versus intended use of the technology
- Changes in efficiency in completed tasks with support of technology
- Study actual benefits of using the system
- Study identified risks, or difficulties, in using the system

Acceptance by workers of the technology is important for any industry that is looking to adopt a new technology. The actual users of the technology have to believe that the product works and helps them do their job better in order for them to accept using it while on the job. The pilot study would allow for examining how easily, or difficult, the technology is adopted on the job by the users. It can also help to see if the users are comfortable with using the technology and if the technology is being used for its intended use or other uses.

The pilot study will also allow for examining actual changes in the efficiency in which tasks are completed. This is part of studying the actual benefits of using the system. Other areas that would be examined to identify benefits or difficulties in using the system would be ease of accessing information needed to complete a task, any changes in the damages associated with an event, reduction of associated health risks, and association with change in patient events related to facility events.

A pilot study would allow for ensuring the system is used for its intended purpose and allow for modifications to the framework and GUIs. Depending on the initial results of a pilot study a secondary or additional pilots with redesigns may be needed. The pilot study(s) would help to organize actual evidence of benefits for adoption and any improved efficiencies caused by the technology's use. A series of questionnaires, interviews, and meetings before, during, and after implementation of the technology would need to be conducted with the actual users, facility managers, and clinical administration to gather data of perception of use. For quantitative data, responses to events can be timed, the quantity of work completed and productivity of staff can be examined based on records of work completed, and changes to patient safety can be examined by studying healthcare related infections and other patient safety events that can be connected to facility related work.

Adoption into Existing Facilities

One of the assumptions of the research is that information would be available for the facility and the proper information is available and captured throughout the facility's lifecycle. For new facilities, being built from the ground up, and especially those that have BIM built into their processes, this framework would be able to be used with little additional upfront effort. The truth is that many facilities that are in use do not have this information readily available. Older facilities, or facilities that are being updated but not built from scratch, do not have the information for the framework or a BIM available. This is an issue for adopting the framework across the industry. Method for best organizing information of existing healthcare facilities would need done to determine how best to implement the framework or a modification of the framework in these buildings.

Uses Outside of Healthcare Implementations

There lays an opportunity to aid in the management of other complex facilities that are dependent on effective management and maintenance of complex systems. Other industry sectors that may see benefit include data centers, laboratory buildings, and plant facilities such as power plants, oil refineries, and production plants. Any facility that relies on efficient and effective facility management to maintain normal operations can potential benefit from the principles discussed in this research of improving communication and information exchange mechanisms through the facility's lifecycle. Beyond singular building or campus applications the ideas presented in the development of this framework can also be applied to urban infrastructure design and maintenance. These are complex systems that require troubleshooting and maintenance at a macro scale but the methods of analysis can still apply.

REFERENCES

Akcamete, A., Alkinci, B., Garrett, J.H., Jr. (2009), "Motivation for Computational support for Updating Building Information Models (BIMs)", Workshop on Computing in Civ. Eng. 2009, 523—532.

Alhir, S.S. (1998), *UML in a Nutshell: A Desktop Quick Reference*. O'Reilly and Associates, Inc. Sebastopol, CA.

American Society of Healthcare Engineers (ASHE) (2011a). *ASHE Industry Organizations*. <www.ashe.org/advocacy/organizations/> (Feb. 1, 2011).

American Society of Healthcare Engineers (ASHE) (2011b), *ASHE Reports*. <http://www.ashe.org/resources/reports> (Aug. 7, 2011).

Ashcraft, H. (2007), "Building Information Modeling: A Framework for Collaboration" American Bar Association Forum on the Construction Industry, October 25 & 26, 2007, Newport, RI.

Association for Health Research and Quality (AHRQ). (2010), "Users Guide: Version 1.1: AHRQ Common Formats for Patient Safety Organizations" AHRQ Common Formats Version 1.1 – March 2010 Release | Users Guide.

Bates, D.W. Gawande, A.A. (2003), "Improving Safety with Information Technology," The New England Journal of Medicine, 348 (25): 2526-2534.

Bigelow J.H., Fonkych, K., Girosi F. (2005), "Technical Executive Summary in Support of 'Can Electronic Medical Record Systems Transform Healthcare?' and 'Promoting Health Information Technology'," Health Affairs, Web Exclusive, September 14.

Blobel, B. (2011), "Ontology driven health information systems architectures enable pHealth for empowered patients", International Journal of Medical Informatics, 80 (2011):e17-e25.

Bobillo, F., Delgado, M., Gomez-Romero, J. (2008), "Representation of context-dependent knowledge in ontologies: A model and an application", Expert Systems with Applications, 35 (2008):1899-1908.

buildingSmart. (2012) "Model – Industry Foundation Classes", *buildingSmart International* <<buildingsmart.com/standards/ifc>> retrieved on April 19, 2012.

Clements-Croome D. (2003) "Environmental Quality and the Productive Workplace," CIBSE/ASRAE Conference (24-26 Sept).

Chandrasekaran, B., Josephson, J.R., Benjamins, V.R. (1999), "What are Ontologies, and Why Do We Need Them?" IEEE Intelligent Systems, 1094-7157/99, 20-26.

Chaudhry, B., Wang, J., Wu, S., Maglione, M., Mojlca, M., Roth, R., Morton, S.C., Shekelle, P.G. (2006), "Systematic Review: Impact of Health Information Technology on Quality, Efficiency, and Costs of Medical Care," Annals of Internal Medicine. 144(10):742-752.

Chaudhury, H., Mahmood, A., Valente, M. (2009), "The Effects of Environmental Design on Reducing Nursing Errors and Increasing Efficiency in Acute Care Settings: A Review and Analysis of the Literature", Environment and Behavior, 41(2009):755-786.

Crystal, A., Ellington, B. (2004), "Task analysis and human-computer interactions: approaches, techniques, and levels of analysis," Proceedings of the Tenth Americas Conference on Information Systems, New York, New York, August.

Cote, R. (2009), *NFPA 101: Life Safety Code Handbook 2009*. National Fire Protection Association (NFPA).

Deng, Z.M., Li, H., Tam, C.M., Shen, Q.P., Love, P.E.D. (2001), "An application of internet based project management system," Automation in Construction, 10 (2001):239-246.

Department of the Army (DOA). (2006), "Failure Modes, Effects, and Critically Analyses (FMECA) for Command, Control, Communication, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities" Technical Manual (TM) 5-698-4, 29 September 2006.

Devlin, A.S., Arneill, A.B. (2003), "Health Care Environments and Patient Outcomes: A Review of the Literature", Environment and Behavior, 35 (2003):665-694.

Dijkstra K., M. Pieterse, & A. Pruyn (2006) "Physical environmental stimuli that turn healthcare facilities into healing environments through psychologically mediated effects: systematic review," Journal of Advanced Nursing, 56 (2): 166-181.

Dossick, C.S., Neff, G., Homayouni, H. (2009), "The Realities of Building Information Modeling for Collaboration in the AEC Indsutry," 2009 Construction Research Congress, 396-405.

East, E.W. (2012), "Construction Operations Building Information Exchange (COBie)", Whole Building Design Guide, National Institute of Building Sciences, Construction <<www.wbdg.org/resources/cobie.php>> retrieved on March 16, 2012.

Eastman, C.M. (1999), *Building Product Models: Computing Environments Supporting Design and Construction*. CRC Press LLC. Florida.

Eastman, C.M., Teicholz, P., Sacks, R., Liston, K. (2008), *BIM Handbook: A Guide to Building Information Modeling for Owners, Mangers, Designers, Engineers, and Contractors*, John Wiley & Sons, Inc. Hoboken, New Jersey.

Enache-Pommer, E., Horman, M.J., Messner, J.I., Riley, D. (2010), "A Unified Process Approach to Healthcare Project Delivery: Synergies between Greening Strategies, Lean Principles, and BIM," Construction Research Congress 2010, 1376-1385.

Environmental Protection Agency (EPA) (2011a), *Clean Air Act | US EPA* <http://www.epa.gov/air/caa/> (Aug. 29, 2011).

Environmental Protection Agency (EPA) (2011b), *Summary of the Clean Water Act | Laws and Regulations | US EPA* <http://www.epa.gov/regulations/laws/cwa.html> (Aug. 29, 2011).

Environmental Protection Agency (EPA) (2011c), *Hospital/Medical/Infectious Waste Incinerators | Technology Transfer Network Air Toxics Website | USA EPA* <http://www.epa.gov/ttnatw01/129/hmiwi/rihmiwi.html> (Aug. 29, 2011).

Environmental Protection Agency (EPA) (2011d), *Office of Underground Storage Tanks (OUST) | US EPA* < http://www.epa.gov/oust/> (Aug. 29, 2011).

Facility Guidelines Institute (2006), *Guidelines for Design and Construction of Healthcare Facilities*. American Institute of Architects.

Food and Drug Administration (FDA) (2011), U.S. Food and Drug Administration <http://www.fda.gov/> (Aug. 29, 2011).

Fowler, M. (2004), *UML Distilled Third Edition: A Brief Guide to the Standard Object Modeling Language.* Pearson Education, Inc. Boston MA.

Fruchter, R., Schrotenboer, T., Luth, G.P. (2009), "From Building Information Modeling to Building Knowledge Model," Proceedings of the 2009 ASCE International Workshop on Computing in Civil Engineering, June 24-27, 2009, Austin, TX, pp. 380-389.

Fuller, S. (2010), "Life-Cycle Cost Analysis (LCCA)," Whole Building Design Guide, National Institute of Building Sciences. Retrieved on 1-19-2010 <http://www.wbdg.org/resources/lcca.php>.

Gallaher, M.P., O'Connor, A.C., Dettbarn, J.L. Jr., Gilday, L.T. (2004), "Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry" NIST GCR 04-867, U.S. Department of Commerce Technology Administration; National Institute of Standards and Technology (NIST).

Georgakopoulos, D, Hornick, M, Sheth, A. (1995), "An Overview of Workflow Management: From Process Modeling to Workflow Automation Infrastructure." Distributed and Parallel Databases, 3(1995): 119-153.

Goedert, J., Meadati, P. (2008), "Integrating Construction Process Documentation into Building Information Modeling." Journal of Construction Engineering and management, 134(7): 509-516.

Guo, H., Heng, L., Li, Y., Huang,T. (2008), "Lifecycle Management of Construction Projects Based on Virtual Prototyping Technologies", in Proc. Of 12th International Conference on Computers in Civil and Building Engineering. October 16-18, 2008, Beijing, China, Tsinghua University Press.

Gruber, T. (1993), "A Translation Approach to Portable Ontology Specifications", Knowledge Acquisition, 5(2), 199-220.

Grundy, T. Brown, L. (2002). *Strategic Project Management: Creating Organizational Breakthroughs*. Thomson: London.

Gruninger, M. Fox, M.S. (1995), "Methodology for the Design and Evaluation of Ontologies" Proceedings of the Workshop on Basic Ontological Issues in Knowledge Sharing, IJCAI-95, Montreal.

Hao, Q., Xue, Y., Shen, W., Jones, B., Zhu, J. (2010), "A Decision Support System for Integrating Corrective Maintenance, Preventative Maintenance and Condition-based Maintenance." Construction Research Congress, 470-479.

Harris, P., McBride, G., Ross, C., Curtis, L. (2002), "A Place to Heal: Environmental Sources of Satisfaction Among Hospital Patients", Journal of Applied Social Psychology, 32(6):1276-1299.

Hillestad R, Bigelo J, Bower A, Girosi F, Meili R, Scoville R, and Taylor R. (2005) "Can Electronic Medical Record Systems Transform Healthcare? An Assessment of Potential Health Benefits, Savings, and Costs," Health Affairs, 24(5).

Humphreys, H., Johnson, E.M., Warnock, D.W., Willatts, S.M., Winter, R.J., Speller, D.C. (1991), "An outbreak of aspergillosis in a general ITU", The Journal of Hospital Infection, 18(3):167-177.

Iftikhar, S., Nawaz, F., Ahmad, H.F., Fatima, K. (2010), "Efficient discovery of OWL-S based HL7 compliant healthcare web services profiles," 2010 6th International Conference on Emerging Technologies (ICET), pp. 287-292.

Imam, F., MacCaull, W., Kennedy, M.A. (2007), "Merging Healthcare Ontologies: Inconsistency Tolerance and Implementation Issues", 20th IEEE International Symposium on Computer-Based Medical Systems, 20-22 June 2007, Maribor: 530-535.

International Code Council (ICC) (2009), *2009 International Building Code*, International Code Council, Washington DC.

Iwen, P. C., Davis, J. C., Reed, E. C., Winfield, B. A., Hinrichs, S. H. (1994). "Airborne fungal spore monitoring in a protective environment during hospital construction, and correlation with an outbreak of invasive aspergillosis", Infection Control and Hospital Epidemiology, 15(5):303-306.

Johnson Controls (2011). <http://www.johnsoncontrols.com> (Apr. 25, 2011).

Katranuschkov, P., Gehre, A., Scherer, R.J. (2003), "An Ontology Framework to Access IFC Model Data". ITcon, 8(2003): 413-437.

Khanzode, A., Fischer, M., Reed, D. (2008), "Benefits and Lessons Learned of Implementing Building Virtual Design and Construction (VDC) Technologies for Coordination of Mechanical, Electrical, and Plumbing (MEP) Systems on a Large Healthcare Project." ITcon, 13(2008): 324 – 342.

Kim, H., Grobler, F. (2007), "Building Ontology to Support Reasoning in Early Design", Computing in Civil Engineering 2007, Proceedings of the 2007 ASCE International Workshop on Computing in Civil Engineering, 151-158.

Lavy, S. Shohet, I.M. (2007). "Computer-Aided Healthcare Facility Management", J. of Computing in Civ. Eng., 21(5):363-372.

Lee, J.S., Min, K.M., Lee, Y.S., Kim, J.H., Kim, J.J.(2008), "Building Ontology to Implement The BIM (Building Information Modeling) Focused on Pre-Design Stage", The 25th International Symposium on Automation and Robotics in Construction. June 26-29, 2008: 350-354.

Lima, C., El-Diraby, T., Stephens, J. (2005), "Ontology-based Optimization of Knowledge Management in E-Construction". ITcon, 10(2005):305-327.

Loo, V.G., Bertrand, C., Dixon, C., Vitye, D., DeSalis, B., McLean, A.P., et al. (1996), "Control of construction-associated nosocomial aspergillosis in an antiquated hematology unit", Infection Control and Hospital Epidemiology, 17(6), 360-364.

Lucas, J. Bulbul, T., Thabet, W. (2012), "A Product Model to Support Healthcare Facility Information Management." J. of Automation in Construction (Submitted for review)

Lucas, J., Bulbul, T., Thabet, W., Anumba, C. (2012), "Case Analysis to Identify Links between Facility and Healthcare Delivery Information in a Hospital Setting." J. of Architecture Engineering (Submitted for review)

Lucas, J. Bulbul, T., Anumba, C. (2012), "Gap Analysis on the Ability of Guidelines and Standards to Support the Performance of Healthcare Facilities." J. of Performance of Constructed Facilities. (Submitted for review)

Lucas, J. Bulbul, T., Thabet, W. (2011a), "A Lifecycle Framework for Using BIM in Healthcare Facility Management." In: Computer Knowledge Building: CIB W78 W102 2011 Proceedings, 26-28 October, Sophia Antipolis, France.

Lucas J., Bulbul, T., Anumba, C., Messner, J. (2011b), "Evaluating the Role of Healthcare Facility Information on Health Information Technology Initiatives from a Patient Safety Perspective," In: 2011 ASCE International Workshop on Computing in Civil Engineering, 19-22 June, Miami Fl, USA.

Lutz, B., Jin, J., Rinaldi, M.G., Wickes, B.L., Huycke, M.M. (2003) "Outbreak of invasive Aspergillus infection in surgical patients, associated with a contaminated air-handling system", Clinical Infectious Diseases, 37(6): 786-793.

MacDonald, I., ed. (2004). *The CMS Hospital Conditions of Participation*. HCPro, Inc.: Marblehead, MA.

Marquis, H. (2008), "Fault Tree Analysis Made Easy," itSM Solutions, Weekly Newsletter, vol. 4.47, November 26. << http://www.itsmsolutions.com/newsletters/DITYvol4iss47.htm>> *retrieved on April 28, 2011.*

McDonald, L.C., Walker, M., Carson, L., Arduino, M., Aguero, S.M., Gomez, P., et al. (1998), "Outbreak of Acinetobacter spp. bloodstream infections in a nursery associated with contaminated aerosols and air conditioners", The Pediatric Infectious Disease Journal, 17(8): 716-722.

Miller, K., ed. (2004). Environment of Care Handbook: Improving Healthcare Quality and Safety, 2nd Edition. Joint Commission Resources, Illinois, USA.

Mohammadpour, A., Anumba, C., Bulbul, T., Messner, J. (2012), "Facilities Management Interaction with Healthcare Delivery Process," Construction Research Congress 2012: construction Challenges in a Flat World, May 21-23, West Lafayette, IN, USA; 728-736.

National Science Foundation (NSF). (2003) Facilities Management and Oversight Guide. July 31, 2003.

Notifier (2011). Honewell Inc. <http://www.notifier.com> (Apr. 25, 2011).

Noy, N., McGuinness, D. (2001), "Ontology Development 101: A Guide to Creating Your First Ontology" Stanford Knowledge Systems Laboratory & Stanford Medical Informatics, Technical Report KSL-01-05, Technical Report SMI-2001-0880; 1-25.

Object Management Group (OMG) (2011), "Business Process Modeling 1.2" <<http://www.omg.org/spec/BPMN/1.2/>> retrieved on April 26, 2011.

Occupational Safety and Health Administration (OSHA) (2011), *Safety and Health Topics: Healthcare Facilities* <http://www.osha.gov/SLTC/healthcarefacilities/index.html> (Aug. 29, 2011).

Oren, I., Haddad, N., Finkelstein, R., Rowe, J.M. (2001), "Invasive pulmonary aspergillosis in neutropenic patients during hospital construction: Before and after chemoprophylaxis and institution of HEPA filters", American Journal of Hematology, 66(4): 257-262.

Ospina-Alvarado, A.M. Castro-Lacouture, D. (2010), "Interaction of Processes and Phases in Project Scheduling Using BIM for A/E/C/FM Integration," Construction Research Congress 2010: Innovation for Reshaping Construction Practices, pg. 939-948.

Petrinja, E., Stankovski, V., Turk, Z. (2007) "A provenance data management system for improving the product modeling process," Automation in Construction, 16(2007):485-497.

Rodriguez, M., Favela, J., Gonzalez, V.M., Munoz, M.A. (2003), "Agent Based Mobile Collaboration and Information Access in a Healthcare Environment." Proceedings of Workshop of E-Health, Applications of Computing Science in Medicine and Health.

Ryan, A. (2006). "Towards Semantic Interoperability in Healthcare: Ontology Mapping from SNOMED-CT to HL7 version 3" Australasian Ontology Workshop, Hobart, Australia: Conferences in Research and Practice in Technology (CRPIT), Vol. 72 M.A. Orgun and T. Meyer Ed.

Schevers, H., Mithchell, J., Akhurst, P., Marchant, D., Bull, S., et.al. (2007), "Towards Digital Facility Modelling for Sydney Opera House using IFC and Semantic Web Technologies". ITcon, 12(2007):347-362.

Sehulster, L., Chinn, R.Y.W. (2003), "Guidelines for Environment Infection Control in Health-Care Facilities," Centers for Design Control and Prevention (CDC) Healthcare Infection Control Practices Advisory Committee (HICPAC), U.S. Department of Health and Human Services, Atlanta, GA, USA

Sheth, A.A., Price, A.D.F., Glass, J. (2010), "BIM and refurbishment of existing healthcare facilities." Egbu, C (ed.). Proceedings of the 26th Annual ARCOM Conference, 6-8 September, ARCOM, Leeds, United Kingdom: 1497-1506.

Shoemaker, L.K., Kazley, A.S., White, A. (2010), "Making the case for evidence-based design in healthcare: a descriptive case study of organizational decision making," Health Environments Research and Design Journal, 4(1):56-88.

Staub-French, S., Fischer, M., Kunz, J., Paulson, B. (2003), "An Ontology for Relating Features with Activities to Calculate Costs". Journal of Computing in Civil Engineering, 17 (2003): 243-254.8

Staub-French, S., Nepal, M.P. (2007), "Reasoning about component similarity in building product models from the construction perspective", Automation in Construction, 17(2007):11-21.

Stichler, J.. (2001), "Creating Healing Environments in Critical Care Units," Critical Care Nursing Quarterly. 24 (3): 1-20.

Stymiest, D. (2011), "Continuous Compliance: Maintaining a constant state of regulatory readiness," J. of Health Facilities Management, 24(5):47-49.

Succar, B. (2009), "Building information modeling framework: A research and delivery foundation for industry stakeholders," Automation in Construction, 18(3):357-375.

Tang, P., Huber, D., Akinci, B., Lipman, R., Lytle, A. (2010), "Automatic reconstruction of as-built building information models from laser-scanned point clouds: A review of related techniques." Automation in Construction, 19(2010):829-843.

Taylor R, Bower A, Girosi F, Bigelow J, Fonkych K, Hillestad R. (2005), "Promoting Health Information Technology: Is There as Case for More-Aggressive Government Action?" Health Affairs, 24(5).

Tsai, W.T., Lee, W.H., Wiezel, A., Sun, X., Li, W. (2009), "Ontology-based Service Composition Framework for Syndicating Building Intelligence," 2009 IEEE Conference on Commerce and Enterprise Computing; 445-452.

Ulrich, R., Quan, X., Zimring, C., Joseph, A., and Choudhary, R. (2004). "The Role of the Physical Environment in the Hospital of the 21st Century: A Once-in-a-Lifetime Opportunity". Report to the Center for Health Design for Designing the 21st Century Hospital Project, September 2004.

U.S. Pharmacopeia (2008), USP (797): Guidebook to Pharmaceutical Compounding – Sterile Preparations. U.S. Pharmacopeia.

Vanlande, R., Nicolle, C., Crus, C. (2008), "IFC and building lifecycle management," Automation in Construction, 18(1):70-78.

Wang, H.H., Boukamp, F., Elghamrawy, T. (2010), "An Ontology-based Approach to Context Representation and Reasoning for Managing Context-sensitive Construction Information", Journal of Computing in Civil Engineering, in press accepted October 8, 2010.

Wharton, C., Rieman, J., Lewis, C., Polson, P. (1993). "The Cognitive Walkthrough Method: A Practitioner's Guide." University of Colorado at Boulder, Department of Computer Science and Institute of Cognitive Science, ICS Technical Report #CU-ICS-93-07.

Woo, J., Wilsman, J., Kang, D. (2010), "Use of As-Built Building Information Modeling," Construction Research Congress 2010, 538-548.

World Health Organization (WHO). (2009), "Conceptual Framework for the International Classification for Patient Safety" World Health Organization.

Zhang, L., Issa, R.R.A. (2011), "Development of IFC-based Construction Industry Ontology for Information Retrieval from IFC Models", Proceedings of the 2011 eg-ice Workshop, University of Twente, The Netherlands July 6-8, 2011.

Appendix A: A Lifecycle Framework for Using BIM in Healthcare Facility Management

This paper is referenced from the *Introduction* chapter in section 1.4. This paper was presented at and included in the CIB W78 – W102 conference held in Sophia Antipolis, Nice, France (Lucas, Bulbul, and Thabet, 2011). The author retains the right to use this work and is available for public download at: http://itc.scix.net/data/works/att/w78-2011-Paper-73.pdf.

This paper serves as a summary introduction to the problem and methodology that is used for the development of the lifecycle information framework.

A LIFECYCLE FRAMEWORK FOR USING BIM IN HEALTHCARE FACILITY MANAGEMENT

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ABSTRACT

Facility Management (FM) is important for healthcare environments to provide adequate and safe treatment to patients by maintaining the physical environment. FM activities are challenged by being disconnected from other processes within a facility's lifecycle. Within healthcare, this disconnect is compounded by insufficient communication with clinical personnel about concurrent clinical operations. Insufficient communication can lead to added risk to patient safety and additional cost to healthcare procedures. This paper describes research on identifying the information across the facility lifecycle and within the facility management and operation stage that are needed to support FM activities in healthcare environments. This information will be used to develop an ontology of integrated FM and clinical information for improving the quality of care in a healthcare setting. The ontology will be linked to a BIM. The ontology will ensure that needed information for facility operations is recorded throughout the lifecycle of the facility and allow facility managers quick access to better organized information. Focus will be on giving an overview of the methods used for determining information needs for FM activities through case study analysis. Case studies are identified through interviews with FM and clinical personnel as well as through literature review. Select cases are documented with Business Process Model Notation (BPMN) allowing for separation of steps and actors within each case. Information needs for each of the steps is determined and overlaid onto the BPMN diagrams. Lastly, the source of each information types is determined. Future work will take the information types, and their origins, determined through this analysis and apply it to an ontology. The ontology will support a BIM-based system for capturing information throughout the lifecycle of the facility in support of the operation and maintenance of the facility.

Keywords: Facility Management, Healthcare, Building Information Modeling, Ontology

1. INTRODUCTION

The maintenance and operation of the physical environment of a hospital and the use of healthcare information technologies are important for the overall quality of care and patient safety. Proper design, maintenance, and care of the physical environment have been connected to reducing patient and staff stress, improving recovery outcomes, and overall healthcare quality (Ulrich et.al., 2004). Research has also shown that Health Information Technologies (HITs) have improved quality of care and patient safety through better adherence to guidelines and protocols (Chaudhry, et.al, 2006), reduce medical errors, decrease health expenses (Hillestad et.al, 2005), improve physician performance, and improve patient outcome (Bates and Gawande, 2003).

Practical implementations of Building Information Modeling (BIM) within healthcare are mostly using BIM as a design and construction planning tool (Sheth, Price, and Glass, 2010; Enach-Pommer et.al.,

2010). Applications of BIM for supporting operation and maintenance activities mostly consist of using laser range finding for creation of as-built models (Goedert and Meadati, 2008), creating as-built models from 2D documents for support of facility geometric information (Woo, Wilsman, and Kang, 2010), and tracking changes within models during the construction process (Akcamete, Alkinci, and Garrett, 2009).

Even with the successes of HIT implementations, there is no research effort connecting healthcare and facility management information within a HIT/BIM capacity to improve the overall operations and maintenance of the healthcare facility. This paper explores the use of BIM and ontology development to support facility information management through the lifecycle of healthcare facilities.

2. HEALTHCARE FACILITY INFORMATION MANAGEMENT

Within the healthcare environment, Facility Management (FM) is in charge of operating and maintaining many complex systems that clinical staff and patients depend on in order to deliver and receive an expected quality of care. In order to maintain these systems, FM must have relevant systems information. This system information comes from various phases during the facility's lifecycle including design, construction, procurement, and delivery (Figure 1). Also during the operation and maintenance of the facility, completing work orders, renovation work, and regular maintenance that occur create more information. Facility managers need to manage all of this information properly in order to support operation and maintenance activities during the operations stage of the facility's lifecycle.

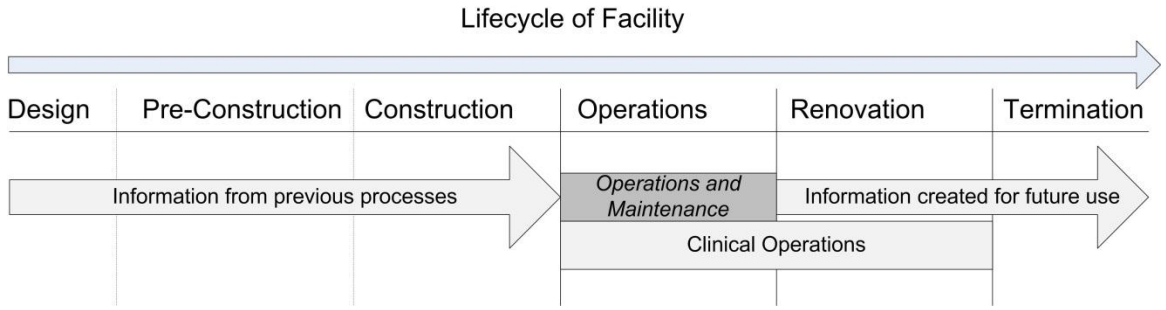

Figure 1: Information management through facility lifecycle

FM operations often need to be undertaken when clinical operations are still occurring with minimal interference to clinical activities. This requires that FM have the adequate information to do their job including air and noise quality requirements, codes and regulations, room occupancies, downtimes, and acceptable times to do work. This requires a bilateral communication and information management on behalf of facility managers. Operations and maintenance do not only rely on building systems information from throughout the facility's lifecycle within healthcare environments, they also must know relevant clinical information about processes that are happening concurrently during the operations phase (Figure 2).

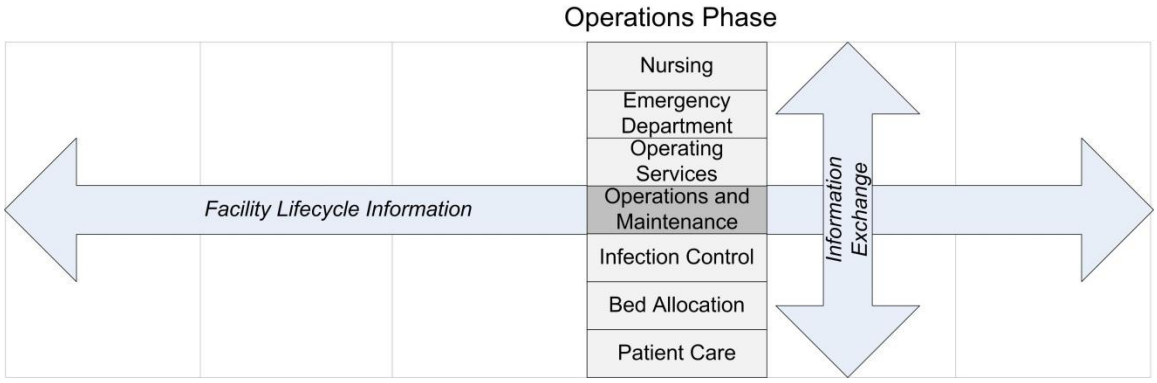

Figure 2: Information exchange within a lifecycle phase

The problem with the requirement for needing access to the vast amounts of information is that it is commonly fragmented over different information management systems and not centrally located. The information created during the building's lifecycle is often stored in different systems and created by different teams with different objectives. These different teams have poorly established lines of communication with little coherence to what information and information formats are needed by other teams completing processes later in the project lifecycle (Ospina-Alvarado and Castro-Lacouture, 2010). Information from earlier in the lifecycle is often not formatted to support operations and maintenance activities. FM as a process is often disconnected from the rest of the facility's lifecycle and the use of BIM, making it difficult to take advantage of BIM within FM activities (Goedert and Meadati, 2008). Building control systems and open contracts add to the complex nature of managing healthcare facility information. Improving communication is the key factor to the success or failure of effectively and efficiently operating, managing, and maintaining a facility with BIM (Eastman et.al., 2008; Gallaher et.al., 2010).

To complicate the situation, healthcare information is stored in completely separate systems with little to no interaction or support of FM processes. If information is not available in a timely manner it can add to the extent of damage, cause a larger down time within a healthcare service, cost the hospital in lost revenue, impact patient care by limiting services, and impact patient safety with effects on environmental quality. Downtime and taking services offline for a period of time may also be critical to the patient's care needs, it is important to have access to information and knowledge when it is needed to limit this downtime.

This research approaches the issues of mismanaged facility management within healthcare facilities by exploring the use of BIM and ontology development. The developed ontology, connected to a BIM, will allow for capturing needed information throughout the facility's lifecycle. Capturing the needed information when it is created will allow for better management of the information during the FM phase and better support FM processes. In order to ensure that the correct information is captured, case-based scenarios dealing with FM processes within healthcare environments are developed and analyzed for information needs.

3. CASE-BASED SCENARIOS

Case-based scenarios are analyzed to understand the type of events that occur and the types of information that are needed in order to properly manage those events. Topics for case-based scenarios are established through interviews with clinical and FM personnel (Table 1). The events were identified as cases were FM personnel would have an interaction with the patient, the patient's care, or a potential influence on the patient's safety. The types of information identified from the case-based scenarios will

be analyzed and tracked to its origin of creation. This will help in developing the ontological framework to capture relevant information throughout the lifecycle of a facility from design through operations and maintenance. The captured information will then be stored and structured for easy retrieval during operation and maintenance events.

Table 1: Case-Based Scenario Topics

	Planned	**Unplanned**
Short Term (< 4 Hours)	○ Changing Filters and Cleaning Coils	○ Climate problem in room ○ Temperature in OR/Recovery out of range ○ Pressure changes in pressure environments ○ Leave Sink Running and Overflow
Mid-Term (4 Hours < 1 Week)	○ Room Renovation ○ Equipment Renovation ○ Planned Maintenance – Limited Utilities	○ Chiller/Boiler goes offline ○ Malfunctioning HVAC unit in OR ○ Pipe Burst (and remediation) ○ Knock off sprinkler head while cleaning (and remediation)
Long Term (>1 Week)	○ Unit Renovation – containment and systems shut down ○ Electrical Renovation	○ Mold or moisture damage previously unknown found during renovation ○ Chiller pipe burst/Air conditioning shut down

The topics for scenarios were separated into planned and unplanned events. Planned events are those of regular maintenance or scheduled upgrade and renovation where systems will be down or spaces will not be occupiable by clinical services. In planned situations, the typical series of events are taken into consideration and are planned for. If systems need to go down, the extent of the work is determined, prepared for, and carefully planned to the last detail. Unplanned events can be crisis situations, or when circumstances arise that are beyond the norm. These types of situations require decisions to be made quickly and information is often needed in a very short period of time. A better framework and capturing of information throughout the lifecycle of a facility would support both planned and unplanned events that involve facility management.

The scenario topics are also broken into the timeframe that they have an effect on clinical processes. Short-term scenarios are those that can be resolved in less than 4 hours, have minimal impact on normal operations and can be taken care of during the weekend or overnight. Mid-term scenarios are those that can be remedied within a week. Lastly, long-term scenarios are those that effect clinical operations for at least a week.

Once the topics for the case-based scenarios are established, selected topics related to the mechanical systems are detailed into a narrative with the processes separated into steps that were taken by various personnel when the situation occurred. Once the narrative is completed a process model is developed in Business Process Model Notation (BPMN). BPMN allows for graphically showing the steps and interactions of the process over different pools representing different parties involved in the event. BPMN also allows for including decision nodes and separation of messages and direction connections of processes (OMG 2011).

An example includes that of water incursion within the operating suite of the hospital caused by a mechanical unit malfunction. Water incursion is noted as one of the biggest threats to infection control and maintaining a healthy environment because of its relation to mold and mildew and their potential to

become airborne pathogens (Sehulster and Chinn, 2003). Because of this, water incursion is taken seriously within healthcare FM. An abbreviated narrative of the case is as follows:

> A critical situation arose when the air-handler unit serving an operating room suite within the hospital malfunctioned. Water, from the chiller plant, was being pumped into the unit with a clogged pipe. Early in the morning during the weekend, the water overflowed the unit and was noticed entering the ceiling within the operating suite over a corridor and operating room. The situation required immediate mediation and determination of cause of damage before any surgery could take place within the operating suite. Care was taken by FM personnel, nursing staff, administration, and infection control to ensure that the situation was taken care of quickly and fully mitigated. Within this process, FM personnel needed to identify the source of the leak, minimize the extent of damage by taking the system offline, and then repairing the system and all damage.
>
> Since the situation occurred during the weekend and early in the morning there were no operations currently underway so no patient was put in immediate danger, however all scheduled surgeries had to be rearranged until the situation was completely resolved. Shutting down the operating suite cost the hospital a large piece of potential revenue. The cost of the physical damage to the building also added to the expenses. Lastly, directly below the leak was the storage space for surgery instruments and tools. In not knowing which tools and supplies might be contaminated from the water damage and particles that may have become airborne, they needed to be disposed of or re-sterilized. Expenses reached over $7 Million in materials and supplies with other expenses added from the operating rooms being out of service while the situation was being remedied.

The typical process for the initial response to this type of situation is shown in Figure 3. A clinical staff member reports water dripping from the ceiling to the building call center. The operator logs the call and immediately informs the on-call maintenance mechanic to go to the scene. The goal of the mechanic is to find the leak, control the situation as best possible, and then mitigate the leak or shut down the system. Not all mechanics that are on call within the building call center are knowledgeable of every system's details in the hospital. This means that when they locate the problem, they may not have the knowledge to deal with the situation. This usually requires them to call a systems mechanic who may or may not know the exact process to follow or location of a system shutoff. If the systems mechanic does not know the process or location he would need to look up the appropriate information and then go to the scene, or return the call and explain the proper processes to the maintenance mechanic. In either case, this takes more time for the situation to be mitigated and adds to the risk of the building occupants as well as to the extent of damage. Once the situation is mitigated, the on-call mechanic updates the building call center and the process to make the appropriate repairs can begin.

Water incursion within healthcare facilities can be inadvertently caused by human action, such as accidently knocking a sprinkler head off while pushing a cart of supplies and a ladder down a hallway, or by pipes breaking from age and ware. Ultimately, whatever the cause, the information needed by the mechanic to quickly remedy the situation needs to be structured, stored, and accessible in a way that would allow a more efficient and effective response process. In order to make the process more efficient the information needed to complete tasks needs to be analyzed. This is done by cognitive walkthroughs and task analysis of each task in the scenarios. The cognitive walkthroughs were conducted with healthcare FM personnel to validate the scenarios and conduct task analysis. The task analysis of each scenario helps identify the information and decisions made in both the cognitive and physical tasks completed during the scenario. The types of information are then mapped back to the facility lifecycle to locate the origin of the information. Knowing the origin of the information helps inform the ontological framework for capturing proper information throughout the facility's lifecycle.

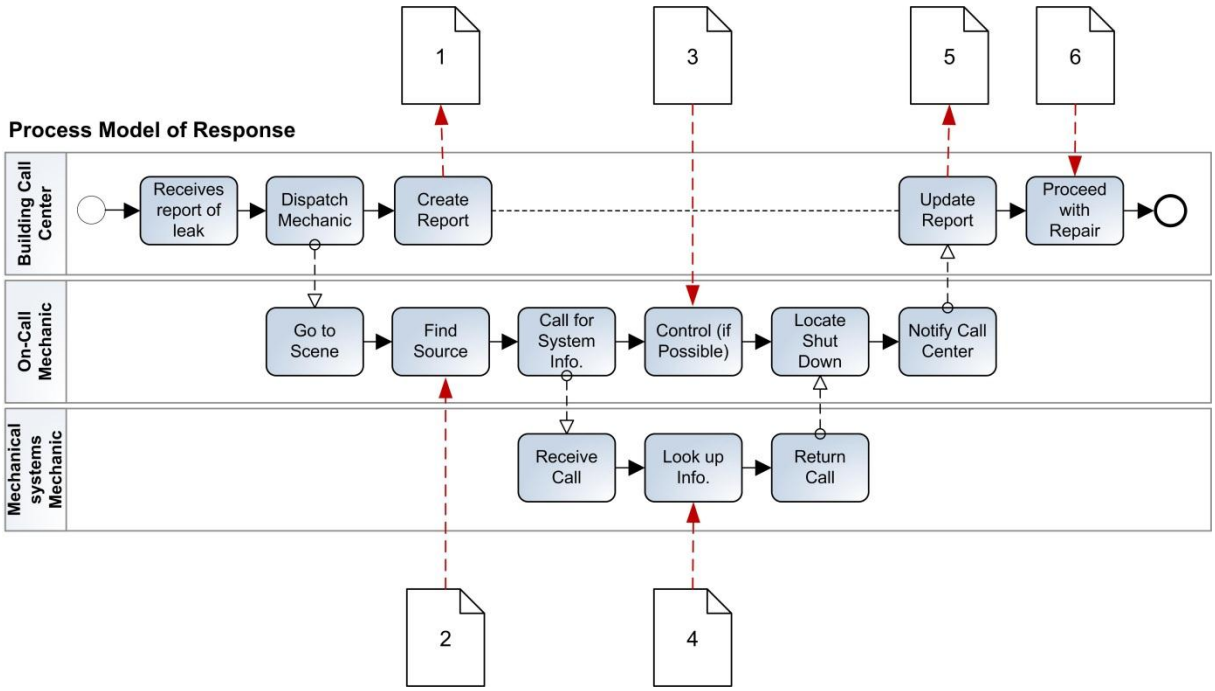

Figure 3: Process Model with Identified Information Needs

The information types needed for the scenario within Figure 3 are (1) work order information during the "create report" process, (2) systems information for the area that can cause the reported problem for "find source", (3) available tools or methods to control the situation during "control", (4) mechanical system plans and shut-down procedures from manufacturer specifications during "look up info.", (5) work orders (modifying created work order in #1) during "update report", and (6) repair procedures and protocols from the hospital's emergency operations plan as well as systems information to "proceed with repair". The details of each information type that is referenced during the identified process are listed in Table 2. They are also mapped to the lifecycle stage where the information originates from.

Table 2: Information details and origins

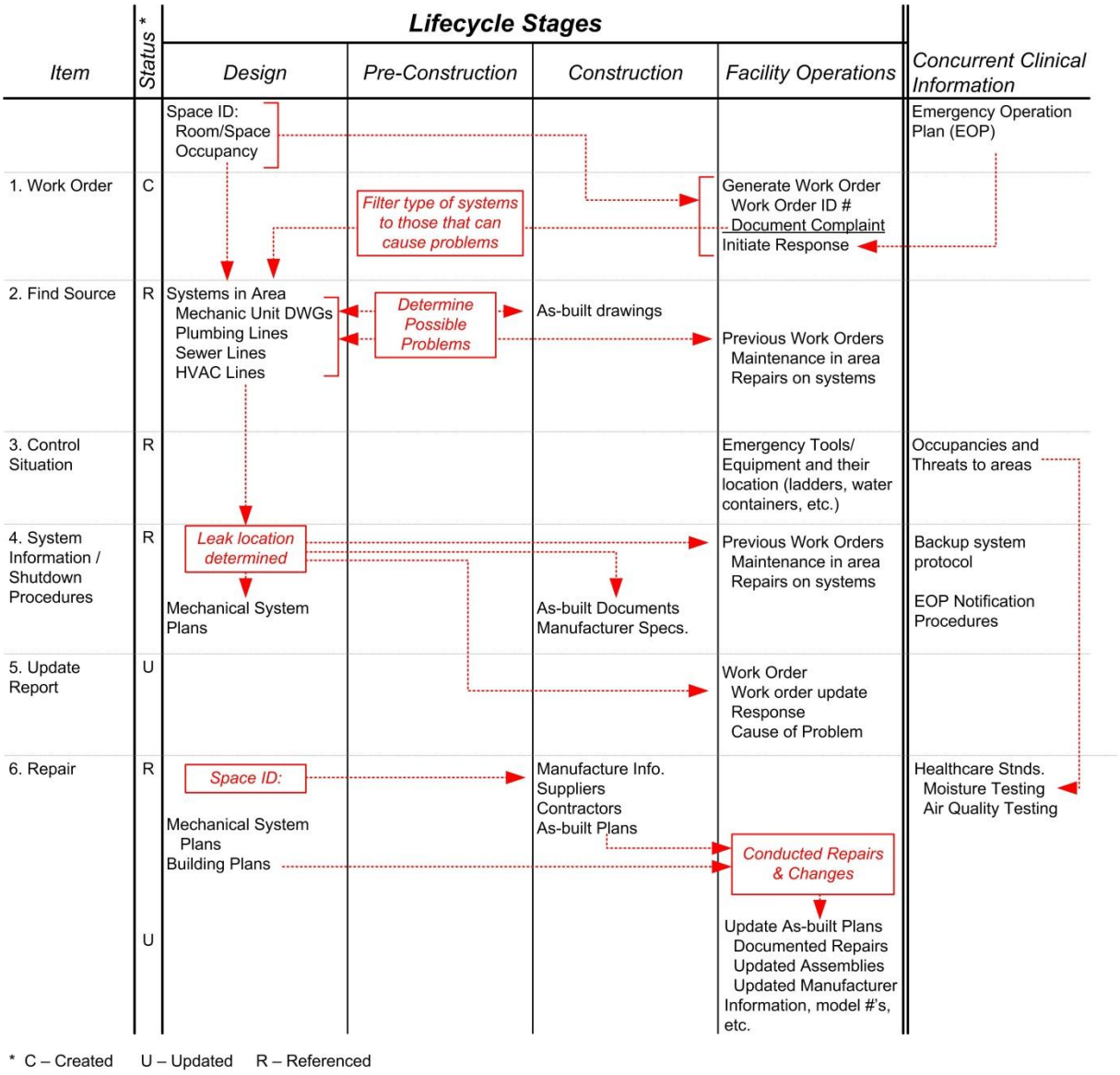

Table 2 shows the type of information that responding personnel would need to reference as well as the specific details that they are looking for within each step of the response. It also links each piece of information back to a phase of the facility's lifecycle. With knowing the specific types of information that are being looked at and where the information came from, an ontological framework can be then be created and used during the pre-construction, construction, and facility operation phase of the facility's lifecycle to capture the needed information.

4. ONTOLOGY DEVELOPMENT

A process to develop an ontology similar to the one described by Noy and McGuiness (2001) will be used in the ontology development. The scope of the ontology will deal with information that is needed to support FM events within healthcare at the systems level. This includes the capturing of the information throughout the lifecycle of the facility at the information's origin. The ontology will be connected to a modeled environment to spatially orientate necessary information. The task analysis of the developed

scenarios will be used to help compile the needed types of information. For the purpose of the research the ontology will focus on supporting events related to mechanical systems but be expandable for future inclusion of other systems.

Competency questions will be developed and used to aid in both the design and evaluation of the ontology. Competency questions are questions that the information supplied by the ontology must be able to handle (Gruniger and Fox, 1995). Some competency questions that will be used to help ensure the ontology will support the needed activities are:

What systems in a location may cause water to be leaking?
How do you shut down a system?
What spaces/rooms would be affected if the system goes offline?
What is the occupancy and use of the spaces?
Who needs to be notified?

Capturing the needed information throughout the facility's lifecycle will help integrate the design, construction, and facility management phases and better support FM personnel in dealing with different FM events. The ontology and information included in the framework will not only help FM personnel with initial response and finding needed system information but also aid in determining extent of work to be completed, scheduling repairs, and having access to supplier and contractor information.

5. ONTOLOGICAL FRAMEWORK IN MODEL

Once the ontology is developed it will be connected to a model with specific instances of the classes being populated with information relevant to mechanical systems. This will help to test the ontology's functionality, utility, and usefulness. It will also help validate the ontology by being able to visualize its functionality with FM personnel. A Graphical User Interface (GUI) will be developed and connected to the ontological framework and model to allow accessing, querying, and editing information. Quick access to information is important so care will be taken to allow for an easy to use interface and ensuring the adequate information is returned to the user. The ontological framework will be connected to a BIM to allow for a spatial organization of the modeled information. This will help with locating information, editing existing information, and updating information (Figure 4).

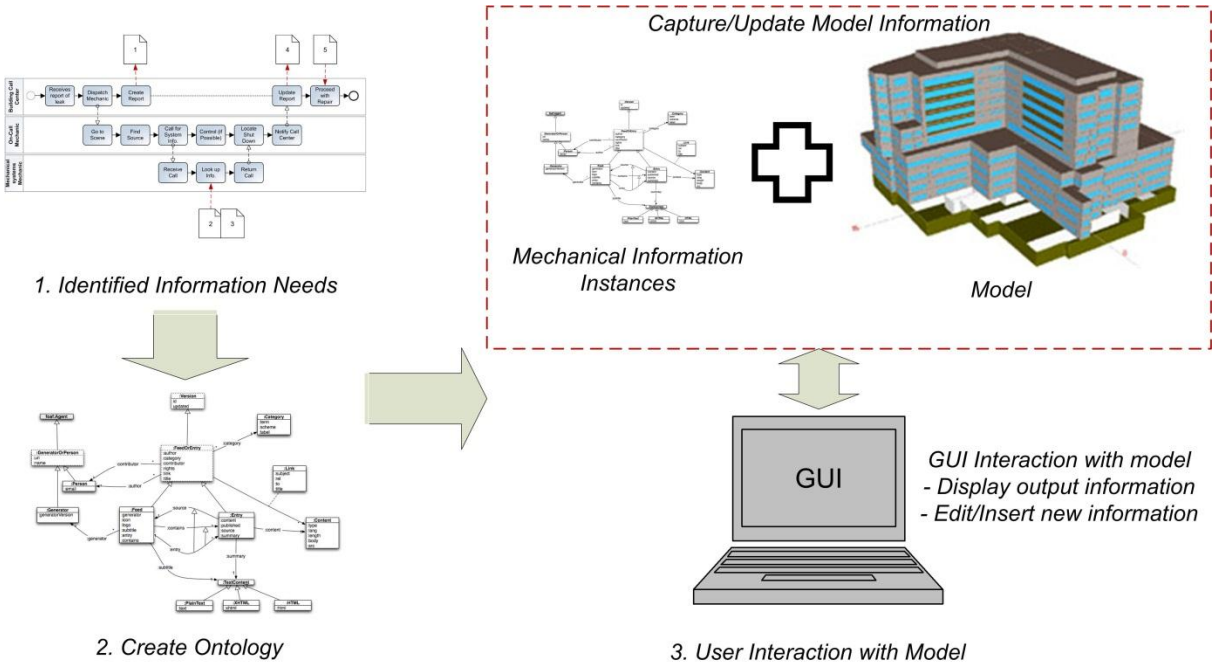

Figure 4: Process Framework

6. DISCUSSION

The goal of the research is to offer a better method of managing needed information for supporting the operation and maintenance phase of the facility by capturing and storing the needed information throughout the lifecycle of the facility. In organizing the information in a modeled environment, the hope is that it will reduce time and effort on the part of a mechanic doing the work by having all the information on hand. It can also help in modifying workflows to be more efficient and effective. The current stage of work is the case-based scenario analysis. Once this stage is completed, the ontology will be created. Instances of the classes will then populate the taxonomy created within the ontology and tied to the BIM as a prototype for accessing the information. The prototype will be used to validate the ontology as well as gauge the effectiveness, utility, and usefulness of the model-based system facility information system within the healthcare industry. The analyzed processes are specific to the healthcare facility that is being consulted during the research and some details may vary depending on the facility. The overall processes should be similar enough to support workflows in other healthcare facilities. At a minimum, the information needed to support the processes would be the same. Future research can compare other facility's processes and workflows to those used in developing the ontology to see if the system can be used and determine what modifications are needed to adapt it for wider use.

Ultimately, a full system would work on a simple tablet or hand held device to allow quick access to the knowledge at the scene of the event. The handheld system can allow for possible work flow steps and also record process steps and information about the taken actions back to the work order system. This handheld system would be tied to a central facility information management system that is controlled by office personnel who have control of editing existing model data and inputting new information (Figure 5).

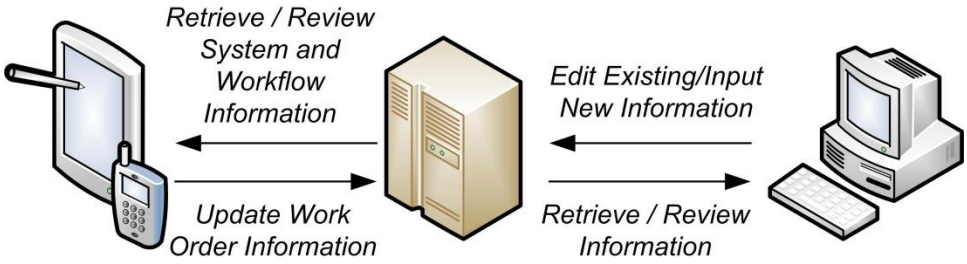

Figure 5: Future Work – Handheld Capabilities

The perceived benefits of the work include an organizational framework to allow for more effective facility information management by improving horizontal and vertical communication needs through a healthcare facility's lifecycle. In the long run, such a system can aid in reducing costs of events to healthcare systems and reduced patient safety risk. Future work may include expansion of the information tracking to help improve efficiencies within other stages of the facility lifecycle and modification of the ontology to support applications in other industries.

REFERENCES

Akcamete, Asli, Burcu Alkinci, and James H. Garrett, Jr. (2009) "motivation for Computational support for Updating Building Information Models (BIMs)", *Workshop on Computing in Civ. Eng. 2009*, 523—532.

Bates, D.W. and A.A. Gawande. (2003) "Improving Safety with Information Technology" *The New England Journal of Medicine*, 348 (25): 2526-2534.

Chaudhry, Baslt, Jerome Wang, Shinyl Wu, Margaret Maglione, Walter Mojlca, Elizabeth Roth, Sally C. Morton, and Paul G. Shekelle, (2006). "Systematic Review: Impact of Health Information Technology on Quality, Efficiency, and Costs of Medical Care," *Annals of Internal Medicine*. 144(10):742-752.

Eastman, Charles M., Paul Teicholz, Rafael Sacks, and Kathleen Liston. (2008). *BIM Handbook: A Guide to Building Information Modeling for Owners, Mangers, Designers, Engineers, and Contractors*, John Wiley & Sons, Inc. Hoboken, New Jersey.

Enache-Pommer, Elena, Michael J. Horman, John I. Messner, and David Riley. (2010) "A Unified Process Approach to Healthcare Project Delivery: Synergies between Greening Strategies, Lean Principles, and BIM," Construction Research Congress 2010, 1376-1385.

Gallaher, Michael P., Alan C. O'Connor, John L. Dettbarn, Jr., and Linda T. Gilday. (2004) "Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry" NIST GCR 04-867, U.S. Department of Commerce Technology Administration; National Institute of Standards and Technology (NIST).

Goedert, J. And P. Meadati (2008) "Integrating Construction Process Documentation into Building Information Modeling." *Journal of Construction Engineering and Management*, 134(7): 509-516.

Gruninger, M. and Fox, M.S. (1995). "Methodology for the Design and Evaluation of Ontologies" *Proceedings of the Workshop on Basic Ontological Issues in Knowledge Sharing*, IJCAI-95, Montreal.

Hillestad R, Bigelo J, Bower A, Girosi F, Meili R, Scoville R, and Taylor R. (2005) "Can Electronic Medical Record Systems Transform Healthcare? An Assessment of Potential Health Benefits, Savings, and Costs," *Health Affairs*, 24(5).

Noy, Natalya and Deborah McGuinness (2001) "Ontology Development 101: A Guide to Creating Your First Ontology" *Stanford Knowledge Systems Laboratory*, Technical Report KSL-01-05 & *Stanford Medical Informatics*, Technical Report SMI-2001-0880; 1-25.

Object Management Group (OMG). (2011) "Business Process Modeling 1.2" <<http://www.omg.org/spec/BPMN/1.2/>> retrieved on April 26, 2011.

Ospina-Alvarado, A.M. and D. Castro-Lacouture. (2010) “Interaction of Processes and Phases in Project Scheduling Using BIM for A/E/C/FM Integration,” *Construction Research Congress 2010: Innovation for Reshaping Construction Practices*, pg. 939-948.

Sehulster, Lynne and Raymond Y.W. Chinn. (2003) “Guidelines for Environment Infection Control in Health-Care Facilities,” Centers for Design Control and Prevention (CDC) Healthcare Infection Control Practices Advisory Committee (HICPAC), U.S. Department of Health and Human Services, Atlanta, GA, USA

Sheth, Amey A., Andrew D.F. Price, and Jacqueline Glass (2010) “BIM and refurbishment of existing healthcare facilities.” Egbu, C (ed.). Proceedings of the 26th Annual ARCOM Conference, 6-8 September, Leeds, United Kingdom, vol. 2, pp 1497-1506.

Ulrich, Roger, Xiaobo Quan, Craig Zimring, Anjali Joseph, and Ruchi Choudhary. (2004). “The Role of the Physical Environment in the Hospital of the 21st Century: A Once-in-a-Lifetime Opportunity”. Report to the Center for Health Design for Designing the 21st Century Hospital Project, September 2004.

Woo, J., J. Wilsman, and D. Kang. (2010) “Use of As-Built Building Information Modeling,” *Construction Research Congress 2010*, 538-548.

Appendix B: Regulation Comparison Matrix

The regulation comparison matrix is referenced from section 2.3 in the *Background and Literature Review* chapter. This comparison matrix was used to analysis the coverage areas of each of the examined codes and standards. Each standard or regulation is listed across the top of the matrix. The topics are listed in each row under category headings. The category headings were created based on sections of the codes and regulations. An 'X' is placed under the standard or regulation next to the topics that each covers. Summary of the completed analysis that this matrix was the basis for is included in section 2.3.

	Standard/Regulation by Organization									
Category/Topic	JC/Environment of Care	NFPA - Life Safety Code	CDC - Guidelines for Environmental Infection Control	Centers for Medicare and Medicaid Services	OSHA	EPA	Food and Drug Administration (FDA)	AIA - Design and Construction of Healthcare Facilities	United States Pharmacopeia - USP 797	IBC
Safety & Safety Management	6			3	3	1	1			
- Risk Assessment	X									
- Preventative Maintenance	X									
- Training (Safety and Procedural)	X									
- Safety Program Review	X									
- Clinical Alarm Functionality	X									
- Hand Sanitation Stations	X									
- Medical Device Safety							X			
- Protection against pathogens					X					
- Protection against burns and cuts					X					
- Slips, Trips, Fall Prevention					X					
- Mercury usage/reduction and safety						X				
- Patient Safety and Rights				X						
- Quality Assessment and Performance				X						
- Medical Service Standards				X						
Security	3									
- Ethical Obligations	X									
- Risk Assessment & Management	X									
- Compliance to JC Standards (patient/worker/facility safety)	X									
Hazardous Materials and Waste	1			2	1			2		
- Sharps containers	X									
- Hazardous material management and handling					X					
- Radiation sources checking				X				X		
- Radiation worker screening				X				X		

Emergency Management	3		2					2		
- Emergency Preparedness Plan	X									
- Risk Assessment	X									
- Emergency Equipment Availability	X							X		
- Recovery and remediation for water-related emergencies			X							
- Remediation for airborne contaminate emergencies			X					X		
Fire Safety		5			1			6		5
- Design requirements		X						X		X
- Egress Requirements for Fire		X						X		X
- Smoke Barriers		X						X		X
- Systems Testing		X						X		
- Fire/Egress Drill and Training		X						X		
- Fire Protection					X			X		X
- Emergency lighting and exits										X
Medical Equipment	4						1	2	1	
- Proper Electrical Supplies	X									
- Not stored in hallway	X									
- Preventative maintenance up to date	X									
- Crash carts stocked and nothing out of date	X									
- Authorized equipment							X			
- Sterility and Sterilization									X	
Fixed equipment (medical and non medical)								X		
Moveable equipment(medical and non medical)								X		

Utilities	3		3	1		5		4		1
- No extension cords (if used of hospital grade)	X									
- Utility room doors closed/locked	X									
- Linen and garbage chutes latched	X									
- Air Quality			X			X		X		
- HVAC System safety maintenance and repair			X					X		
- Water system safety and repair			X					X		
- Waste reduction and safe waste disposal						X				
- Emissions reduction						X				
- Waste water treatment and disposal						X				
- Medical waste reduction and disposal						X		X		
- Maintenance to support occupant and patient safety				X						
- temperature control and ventilation requirements										X
Housekeeping	3		1					2	1	
- Carts not parked to block corridor	X							X		
- Chemicals secured and not left unattended	X									
- Linen cars left covered	X									
- Cleaning and disinfecting standards of medical rooms									X	
- Cleaning and disinfecting standards			X					X		
Design		6		1				10	1	23
- Fire and Egress Design		X						X		X
- Safety Review		X								
- Areas of Refuge		X								X
- Emergency Generators		X						X		X
- Elevator and escalator requirements		X						X		X
- Healthcare design standards		X						X		
- Corridors must be contiguous to an exist (or open to fire safety space of waiting area, nurse's stations, mental health treatment areas, or gift shops.										X

- Waiting area limitations on use								X		X
- Nurses stations can only be used for charting, communication, and related clerical work										X
- Waiting areas and nurses stations must be construction with corridor specifications if open to corridor										X
- Mental health treatment area limitations and specifications								X		X
- Gift shops open to corridor must be less than 500 SF, sprinklered and storage areas must be sprinklered										X
- Designed to promote safety				X						
- Corridor walls must be smoke partitions										X
- Corridor doors must be consistent with fire rating of wall										X
- locks on patient rooms can only obstruct means of egress in mental health facilities										X
- Smoke barriers and compartments required on floors where patients sleep										X
- Sprinklers required throughout building								X		X
- Required sprinkler type specifications										X
- Fire alarm requirements								X		X
- allowable materials and finishes										X
- ramps, handrails, curbs, and guard requirements										X
- Accessibility guidelines										X
- Design of medication compounding rooms									X	
- bathrooms and fixture requirements								X		X
- Mechanical, electrical and plumbing requirements								X		X
- structural design and testing										X

Construction/Renovation			2					1		2
- Infection control risk assessment			X							
- Air sampling requirements			X					X		
- Construction safeguards (site work)										X
- Existing structures										X
Medication Safety	5			1	1		1	7	7	
- stored in right conditions	X						X	X	X	
- refrigerators free of food	X							X		
- refrigerators at right temperature	X								X	
- medication use dates	X								X	
- medical areas locked or secured	X							X		
- pharmacy room design								X		
- medical room air quality									X	
- negative pressure rooms									X	
- Training compounding personnel									X	
- equipment storage and maintenance								X		
- drug administration safety/hazards					X			X		
- environmental standards of medical compounding spaces									X	
- pharmacy management by qualitifed personnel and accurate records				X				X		
Food Safety	3			3			1			
- No medication in refrigerator	X									
- Refrigerator at right temperature	X									
- food at right temperature	X						X			
- Qualified nutritionist required				X						
- diet to meet medical and religious needs available				X						
- nutritional needs to support health				X						

Infection Control			5	2				4		
- Positive and negative room pressures			X							
- disease transmission safety			X							
- Airborne sources and containment specifications			X					X		
- waterborne sources and containment specifications			X							
- steps for epidemiological investigations			X					X		
- personnel to track and record cases				X				X		
- Active plan for controlling infection				X				X		

Appendix C: Evaluating the Role of Healthcare Facility Information on Healthcare Information Technology Initiatives from a Patient Safety Perspective

This paper is referenced from section 2.4 of the *Background and Literature Review* chapter. The paper was presented and included in the *Proceedings of the 2011 ASCE International Workshop on Computing in Civil Engineering, Miami, Florida, June 19-22, 2011* (Lucas et.al., 2011). This paper is included with permission of ASCE for use in author's dissertation.

The paper introduces two industry initiatives for recording patient safety event information. These product models are the *Agency for Healthcare Research and Quality (AHRQ)* "Common Formats" and the *World Health Organizations* "International Classification for Patient Safety". The two initiatives are summarized as to their purpose and what types of information they hold then they are examined for their ability to classify facility information related to the patient safety events. The purpose of this paper is to determine which product model may be helpful in organizing patient safety and hazard information within the proposed healthcare facility information management framework.

Evaluating the Role of Healthcare Facility Information on Health Information Technology Initiatives from a Patient Safety Perspective

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ABSTRACT

Patient safety is a principal factor in healthcare facility operations and maintenance (O&M). Ongoing initiatives to help track patient safety information and record incidents and close calls include *Common Formats* and *International Classification for Patient Safety* (ICPS). Both efforts aim to develop ontologies to support healthcare providers to collect and submit standardized information regarding patient safety events. Aggregating this information is crucial for pattern analysis, learning, and trending. The purpose of this paper is to analyze these existing efforts to see how much facility and facility management information is covered in the existing frameworks and how they can interface with new systems development. This analysis uses documented cases from literature on healthcare associated infections, inputs the data from the cases into the information categories of *Common Formats* and *ICPS*, and identifies gaps and overlaps between these existing systems and facility information. With this analysis, connections to these efforts are identified that serve as a leverage for showing the role of healthcare facility information for assessing and preventing risky conditions. Future work will use these findings and the supported ontology to connect patient safety information to a building model for supporting facility operations and maintenance. The aim is generating and interpreting high-level information to provide effective and efficient patient safety in a healthcare environment.

INTRODUCTION

Patient care and safety is of prime importance to clinical staff within a healthcare environment. The design and function of the physical environment and use of Healthcare Information Technologies (HITs) are two important pieces in providing quality care and ensuring patient safety within a healthcare setting.

Proper design, maintenance, and care of the physical environment has been proven to reduce patient and staff stress, improve recovery outcome, and improve overall healthcare quality (Ulrich et al., 2004). A better indoor working environment has also been linked to better productivity (Clements-Croome, 2003), which can lead to better quality of care. Guidelines exist within the industry, such as those from the U.S. Department of Health and Human Services (Sehulster and Chinn, 2003), and other design standards, to ensure the environment of care is safe, with proper ventilation, systems control, and procedures to help reduce Healthcare-Associated Infections (HAIs) and patient safety events.

The use of HIT applications within healthcare systems as a way of improving patient safety is expanding. Research has shown that HIT has the potential for significant savings, increased safety, and better health (Hilestad et al., 2005; Taylor et al., 2005; Bigelow et al., 2005; Bates and Gawande, 2003). Reducing medical errors and improving patient safety can ultimately save healthcare and related industries $19.5 billion (USD) annually in the United States (Shreve et al., 2010). The improvement to patient safety and reduction of medical errors linked to the use of HIT has led to the federal government passing legislation promoting the use of HIT and to create programs for funding their implementation (Bates and Gawande, 2003).

Integrating facilities and environment information is lacking within existing HIT solutions that deal with patient and clinical information. This paper reviews two HIT ontologies related to patient safety events for their ability to support facility information and explores options for including them in future systems implementation. This is done by applying data from documented case studies of patient safety events on healthcare associated infections which involve a failure on the facility side, into the existing ontologies. The results of this study can help to develop a decision support system that links patient safety concerns with facility management and operational tasks that can be used to help improve patient safety and environmental quality.

PATIENT SAFETY EVENT CASES

Information from two cases involving patient safety events and Healthcare-Associated Infections (HAIs) caused by facility/maintenance issues were found within literature and one case scenario developed through interviews with clinical and facilities staff at Hershey Medical Center, Hershey, PA, were involved in the following analysis. Information for these cases and scenarios were used as inputs into the existing frameworks (Common Format and ICPS) to identify information gaps of environmental and facility information that is important for properly recording incidents and preventing similar situations from happening again.

Case 1: Operating room air-intake duct. A growth of moss on the room and pigeon feces on the window ledge both adjacent to an operating room air-intake duct caused an outbreak of Aspergillus endocarditis (Walsh & Dixon, 1989).

Case 2: Outside construction causes nosocomial aspergillosis. Construction outside the hospital has been associated with concurrent nosocomial aspergillosis in immunocompromised patients. The air conditioners were contaminated due to road construction outside the Medical Center (Walsh & Dixon, 1989).

Case 3: Bacteria growth in air conditioning unit cause legionnaires' disease. Because of lack of regular maintenance to the interior of the in-wall air conditioner units, patients and staff were infected with legionnaires' disease when bacteria became airborne.

HEALTH INFORMATION TECHNOLOGY AND PATIENT SAFETY

There are a few formalisms underway within the healthcare industry to create a central system for capturing and classifying patient safety events and related information within a structured ontology. Two of these initiatives are the Association for Heath Research and Quality's (AHRQ) *Common Format* and the World Health Organization's (WHO) *International Classification for Patient Safety*.

AHRQ – Common Format. The Patient Safety and Quality Improvement Act of 2005 established a framework for voluntary submission of privileged and confidential information to be collectively analyzed in regards to the quality and safety of patient care given in a healthcare setting. The idea is to have the information, from different organizations, in a standardized format to allow the aggregation of data to identify and address underlying causal factors of patient safety problems. The information will be stored in a database where AHRQ in the larger scale or individual hospitals locally can then use the data to analyze statistics and do trending of patterns in regards to patient safety events (AHRQ, 2010).

AHRQ Common Formats allows for capturing the information on different incident types. Associated data for each incident is captured and classified in the Logical Data Model. The Common Format also defines use-cases for developers on how to implement the data model. The processes are captured in a flowchart format to assist with development of data types that need to be recorded for each

incident. The goal of the Common Format is to support standardization so that data collected by different entities are clinically and electronically comparable.

The data model in Common Formats is organized around "`Concern - Event or Unsafe Condition`" class. There are eight main patient safety conditions that are defined as sub-types around it: blood/blood product, device/medical surgical supply, fall, healthcare-associated Infection, medication/other substance, surgery/anesthesia, perinatal and pressure ulcer. Every event has data related to the "`Contributing Factor`", "`Reporter`", "`Patient`", and "`Linked`". For the purpose of this study we focused on describing a case for a Healthcare-Associated Infection (HAI). Figure 1 shows how the information is organized in the Common Formats for HAI (adapted from PSO Privacy Protection Center, 2010).

In this model, the information which needs to be recorded would include the type of infection; if the infection was present at time of admittance (such as from a previous health event) or if it was acquired in the hospital; the source of the infection, if medical procedures were involved; and what types of treatments were given. Each of these details is linked to a data element. The data elements are clearly defined within the Common Formats Data Dictionary that describe their appropriate use within the overall system, the data type, maximum available length, and where the information may be collected from (PSO Privacy Protection Center, 2010).

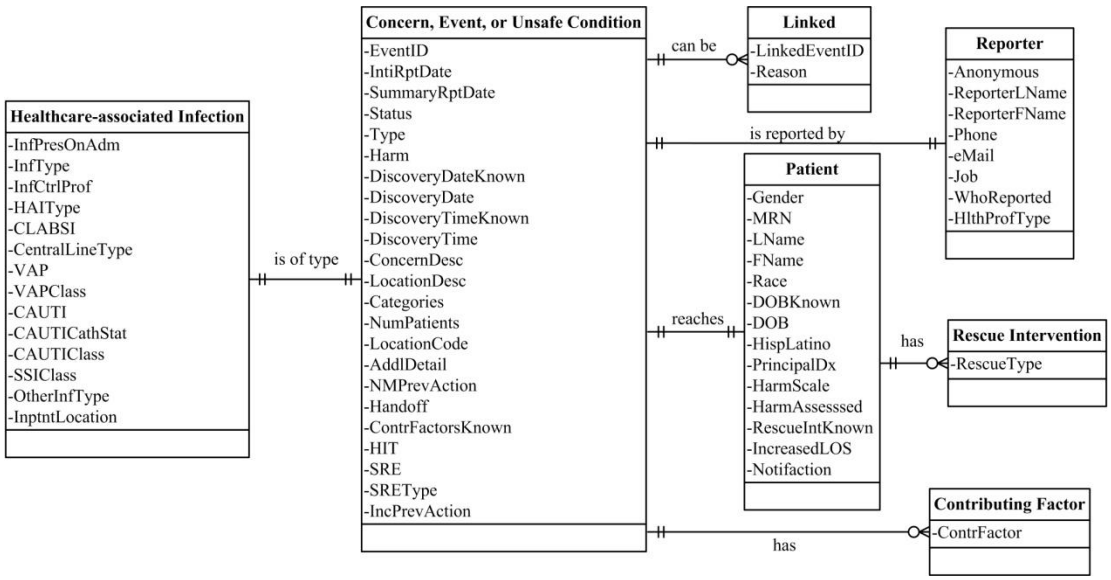


Figure 1. Common Format Logical Data Model for HAI Information.

WHO – International Classification for Patient Safety (ICPS). The WHO formed a Drafting Group that was in charge of developing the conceptual framework for the ICPS. The framework was validated for multiple languages and approved to fit the purpose, and to be meaningful, useful, and appropriate for classifying patient safety data and information. The framework aims at providing a comprehensive understanding of the patient safety domain by representing a continuous learning and improvement cycle emphasizing identification of risk, prevention, detection, reduction of risk, incident recovery and system resilience (WHO, 2009).

At this point, ICPS only focuses on a taxonomy for classifying the patient safety events. It is more of a conceptual framework than a complete data model. On the larger scale the classes are created but the attributes are still in the development process. The taxonomy is based on a conceptual framework, consisting of 10 high level classes: incident type, patient outcomes, patient characteristics, incident characteristics, contributing factors/hazards, organizational outcomes, detection, mitigating factors, ameliorating actions, actions taken to reduce risk. The "incident type" class identifies13 sub-types as

safety events which are: clinical administration, clinical process/procedure, documentation, healthcare associated infection, medication/IV fluids, blood/blood products, nutrition, oxygen/gas/vapor, medical device/equipment, behavior, patient accidents, infrastructure/building/fixtures, resources/organizational management.

For the cases defined in this paper, two incident types in ICPS, healthcare associated infection and infrastructure/building/fixtures, fit the purpose. Figures 2 and 3 (adapted from WHO, 2009) show how these classes are formed.

Actual implementation of both initiatives is ongoing and in development although both offer organizational models and technical information to help with development. Common Formats has a bottom-up approach where attributes for every safety event are specifically defined. The context of the data model only covers hospitals and the model is ready for implementation. The ICPS has a top-down approach, where the context covers all healthcare environments and the model defines large scale relationships first. The focus is on comprehensive classification but the attributes are not yet identified for every class. The ICPS is not implementable yet.

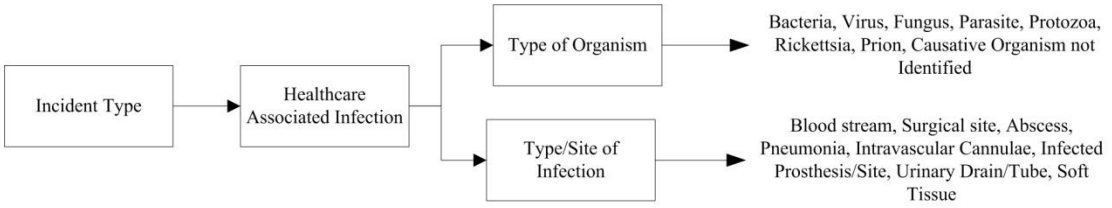


Figure 2. ICPS Class for Healthcare Associated Infection

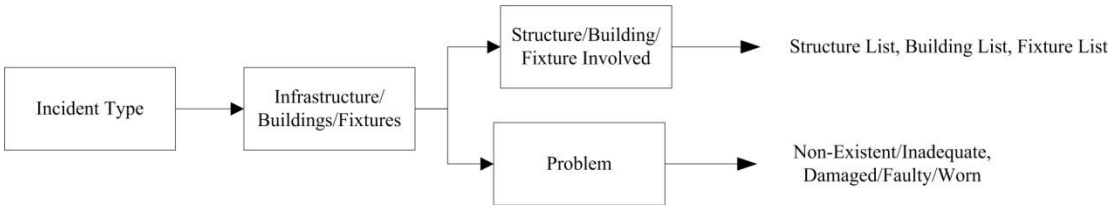


Figure 3. ICPS Class for Structure/Buildings/Fixtures

CAPACITY COMPARISON

The Logical Data Models of Common Formats and Conceptual Framework for ICPS are used for comparison to support facility management information in HIT. The information categories for each of these systems are recorded in Table 1.

In comparing the existing patient safety information data structures for their functionality to assist with facility management and maintenance information, it is first necessary to compare their capacities with each other. Common Format and ICPS are extremely similar in purpose, function, and features. In the early conceptual phases however, ICPS offers more information that can be used to help locate, solve, and inform for future improved practices, facility management tasks and information with its event type of Structure/Building/Fixture.

Within the Common Format logic, the information from the case studies that dealt with locations of the facility and systems within the building would only be stored under the "Contributing Factors" to the event. The case would be filed as an HAI event. Arguably, it would fit better under a separate event type dealing with facilities/maintenance. Research shows that HAI's and other events can be directly linked to maintenance, renovation, and construction (Walsh & Dixon, 1989; Cooper et.al, 2003). These events may be better suited for future planning if they were stored within their own event type. The ICPS allows for contributing issues to the facility.

Another aspect of the ICPS that is missing from the logic of Common Format is that ICPS allows within its framework for determining better actions in the future based on the events. This allows for a type of lessons learned database as the information is input into the system. One of the initiatives for Common Format is that the data would be interpreted at a later time to find trends, behaviors, root causes, and better practices where as ICPS can allow for an ever-growing consistent development of this type of better practices information.

Table 1. Information Categories for Common Format and ICPS

Storage Capability	**Common Format**	**ICPS**
Rescue Intervention (Reduce Risk)	X	X
Contributing Factors to Event	X	X
Reporter	X	
Linked Event or Symptom (Diagnosis)	X	
Patient Information	X	X
Event Type and Information	X	X
Detection		X
Outcomes (harms to patient/ accountability in organization)		X
Ameliorating Actions		X
Types of Events		
Blood	X	X
Device/Supply	X	X
Fall (or accident)	X	X
Healthcare-Associated Infection	X	X
Types of infections	X	X
Treatment Sources	X	
Location Where Appeared	X	X
Medication/IV	X	X
Surgery/Anesthesia	X	X
Pressure Ulcer	X	
Nutrition		X
Documentation		X
Procedure		X
Behavior (Patient or Staff)		X
Infrastructure Building or Fixture (and associated problem)		X
Resources (Organization)		X

Table 2 shows the different types of information directly related to the facility that is available from the cases and can be useful in determining better practices for facility maintenance and operations. Note that patient information, including symptoms, treatments, and other medical information, is omitted from the table as this information is not directly important to facility management and is stored by both Common Format and ICPS.

Table 2. Case Information supported in Ontologies

Information Type	Common Format	ICPS
Building/Room/Space: Operating Room/Patient Room		X
Mechanical System: Air-intake Duct		X
Systems: In-wall Heating/Ventilation/AC Unit		X
Location: Roof/Patient Room		X
Facility Cause: Unclean Filter/Contaminated Intake	X	X
Cause of Infection: Bacteria Growth	X	X

Although both information structures allow for the storage of all information related to facilities within the cases, ICPS appears to allow for better sorting of the information for events caused by facility issues because of the classes of information that allow for Structure/Building/Fixture information. While not all attributes are defined through ICPS, the conceptual framework takes facility information into consideration. To cover all areas of information as marked in Table 2, the attributes for Structure/Building/Fixture would need to take into account aspects of locations and systems throughout the healthcare setting.

DISCUSSION AND FUTURE WORK

The long-term research goals include the development of a model-based system to enable facility managers to improve operations that help to reduce patient safety events related to facility issues. The model-based system would help as a decision support system and planning tool for maintenance tasks. This is envisioned to occur through interfacing with existing systems, both internal and external, to the healthcare facility as well as the model-based system serving as a central depository for key facility information. The purposes of this model-based system would be to help in making decisions in time of crisis with unforeseen facility related events (e.g. malfunctioning HVAC equipment) as well as to aid in better management and scheduling of regular maintenance tasks (e.g. cleaning coils and filters).

The framework for this model-based system will be developed through creating and analyzing decision-trees for documented cases and conditions. Once this analysis is complete, the types of information needed for making certain types of decisions will be known. This information can then be structured to allow for referencing and making future decisions within the model-based system.

Some information types that will be included in this information framework include information from design, engineering, construction, and renovation. These types of information will mostly contain physical location of systems, system warrantee information, operational manuals with required maintenance schedules, and the like. Other information included will be that of best practices, decision support information (for times of crisis), and regulation based information.

The initiatives discussed in this paper can give insight into the types of information needed to support best practices and decision support. Both Common Formats and ICPS can serve as interfaces to inform the system on trends wider than one healthcare facility or campus. Where they can benefit a planning system the most is in serving as the basis for a lessons learned database to support improved practices for facility related HAI's and safety events. Beyond a lessons-learned database, information on patient safety events in a central location can help in trending and finding recurrences to aid infection control and facility personnel to more quickly locate larger problems within a facility.

Other systems that the facility management model-based system may interface with are those dealing with the clinical operations of a building. Bed-tracking and other medical data systems can be connected to the model-based system to send messages of when spaces are available for regular maintenance or help track trends of patient events and locate causes with the physical environment. The interface with other systems can also more easily allow clinical personnel, such as those within infection to control, to link trends of illness and infection to a facility management cause.

The linking of all relevant facility management information to a model-based system that also has the capabilities of interfacing with existing information systems can prove as a valuable HIT to the healthcare industry. The physical environment is a key point to providing quality of care and maintaining that environment requires keeping many systems working properly. A HIT that links patient safety to facility management information can help lead to a reduction of patient safety events, saving the healthcare industry money, and more importantly improving quality of patients' lives.

REFERENCES

Association for Health Research and Quality (AHRQ). (2010) "Users Guide: Version 1.1: AHRQ Common Formats for Patient Safety Organizations" *AHRQ Common Formats Version 1.1 – March 2010 Release | Users Guide.*

Bates, D.W. and A.A. Gawande. (2003) "Improving Safety with Information Technology" *The New England Journal of Medicine,* 348 (25): 2526-2534.

Bigelow JH, Fonkych K, and Girosi F. (2005) "Technical Executive Summary in Support of 'Can Electronic Medical Record Systems Transform Healthcare?' and 'Promoting Health Information Technology'," *Health Affairs,* Web Exclusive, September 14.

Clements-Croome D. (2003) "Environmental Quality and the Productive Workplace," *CIBSE/ASRAE Conference* (24-26 Sept).

Cooper EE, O'Reilly MA, Guest DI, and Dharmage SC. (2003). "Influences of Building Construction Work on *Aspergillus* Infection in a Hospital Setting," *Infection Control and Hospital Epidemiology,* 24(7): 472-476.

Crystal, Abe and Beth Ellington (2004). "Task analysis and human-computer interaction: approaches, techniques, and levels of analysis," *Proceedings of the Tenth Americas Conference on Information Systems.*

Hillestad R, Bigelo J, Bower A, Girosi F, Meili R, Scoville R, and Taylor R. (2005) "Can Electronic Medical Record Systems Transform Healthcare? An Assessment of Potential Health Benefits, Savings, and Costs," *Health Affairs,* 24(5).

PSO Privacy Protection Center (2010). "AHRQ Common Formats Version 1.1: Technical Specifications," Accessed on 12/20/10, website: https://www.psoppc.org/web/patientsafety/version-1.1_techspecs.

Shreve J, Van Den Bos J, Gray T, Halford M, Rustagi K, and Ziemkiewicz E. (2010) "The Economic Measurement of Medical Errors: Sponsored by Society of Actuaries' Health Section," *Milliman Inc.* (June).

Sehulster L and Chinn RYW. (2003) "Guidelines for Environment Infection Control in Healthcare Facilities," Centers for Disease Control and Prevention Healthcare Infection Control Practices Advisory Committee (HICPAC).

Taylor R, Bower A, Girosi F, Bigelow J, Fonkych K, and Hillestad R. (2005) "Promoting Health Informaiton Technology: Is There as Case for More-Aggressive Government Action?" *Health Affairs,* 24(5).

Ulrich R, Quan X, Zimring C, Joseph A, Choudhary R. (2004) "The Role of the Physical Environment in the Hospital of the 21st Century: A Once-in-a-Lifetime Opportunity," Report to the Center for Health Design for *Designing the 21st Century Hospital Project,* September 2004.

Vanlande, Renaud, Christophe Nicolle, and Christophe Crus. (2008). "IFC and Building Lifecycle Management". *Automation in Construction*, 18 (2008): 70-78.

Walsh T.J., and Dixon D.M. (1989) "Nosocomial Aspergillosis: Environmental Microbiology, Hospital Epidemiology, Diagnosis and Treatment," *European Journal of Epidemiology*, 5(2):131-142.

World Health Organization (WHO). (2009 "Conceptual Framework for the International Classification for Patient Safety" World Health Organization.

Appendix D: Case Study 1 – Process Model

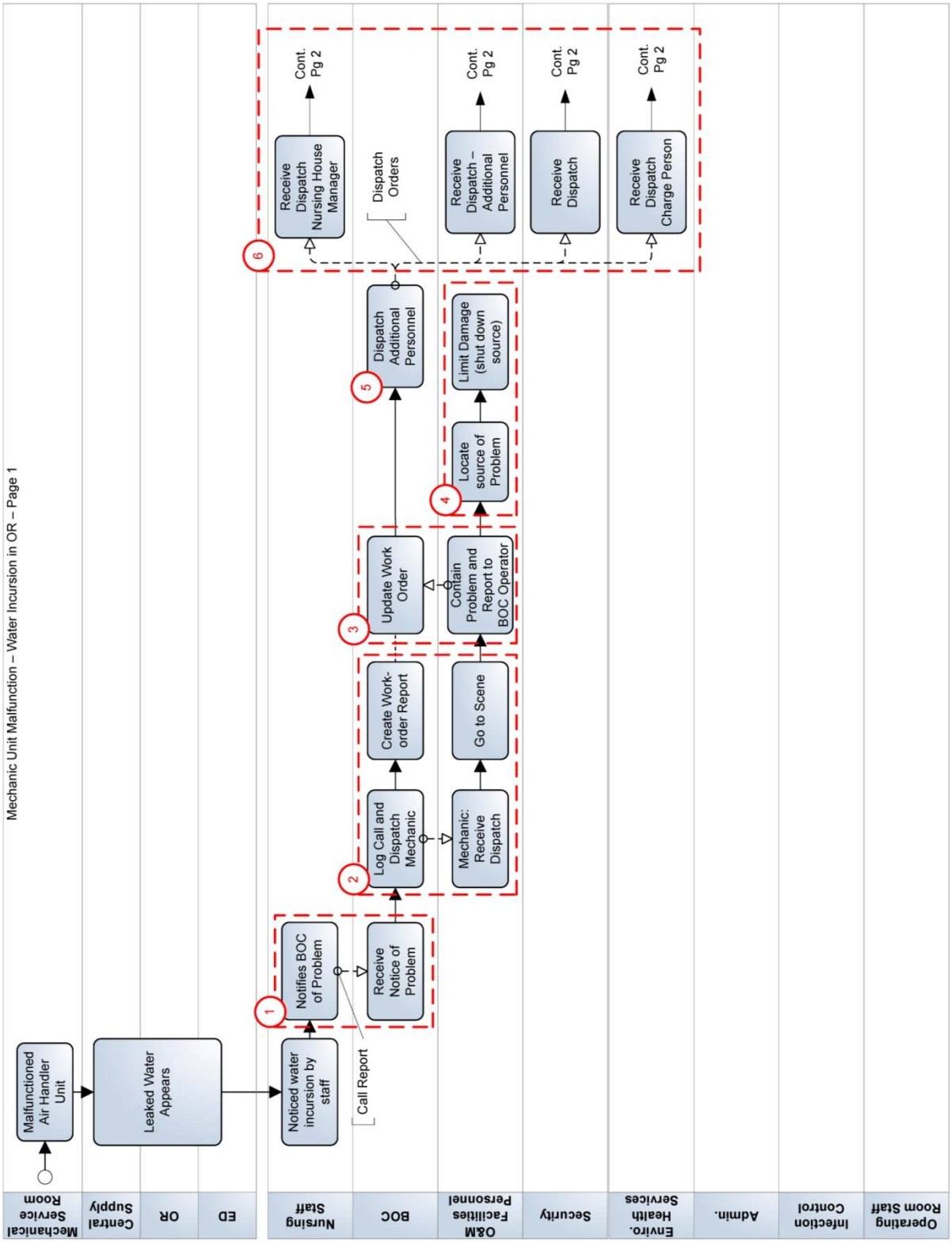
This appendix is referenced in section 3.2 of the document and contains the process model that is used for Case Study 1. The process model is documented in Business Process Model Notation (BPMN) with the use of swim lanes representing the different actors (personnel) involved in the process. The step by step numbered narrative represents the numbers on the three separate pages of the Case Study 1 BPMN. These steps are a broken down representation of the separate tasks that took place during the event described in full narrative in Section 3.2 *Case Narrative*.

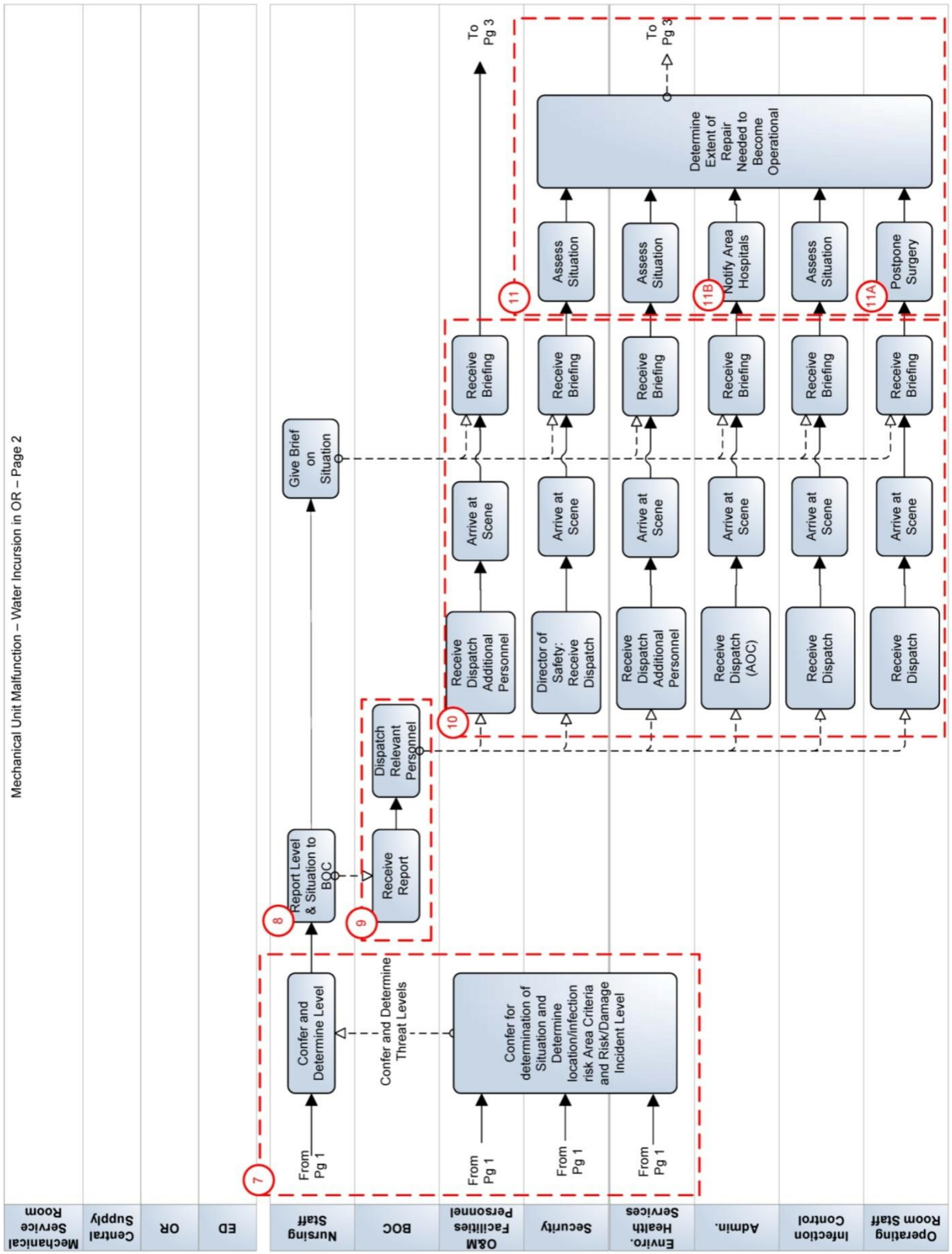
1. Once the leak appears, the nursing staff manager contacts the maintenance call center operator.
2. The operator logs the call, dispatches the on-call first response maintenance mechanic to water incursion reports during the shift, and creates a work-order.
3. The maintenance mechanic goes to the scene to assess the situation, contain the water to try to limit damage, and updates the call center operator to what personnel are needed on the scene.
4. Mechanic attempts to locate the source of the problem and shut down the source if he is able. In this case, the problem was located as an air handler unit over the operating suite and the mechanic had to call a mechanical systems mechanic to determine the proper method of shutting down the system.
5. When the operator receives the initial report, he updates the status within the work order and log book and dispatches the response team.
6. The Nursing House Manager, Security personnel, and Environmental Health Services Charge Person receive the dispatch page to go to the scene.
7. On scene, the response team examines the situation and determines the location/infection risk area criteria and risk/damage incident level (criteria used from emergency operation plan).
8. The Nursing House Manager replies back to the operator with the reported levels and a situation update.
9. The operator receives the call and dispatches other relevant personnel (personnel based on situation). In this case additional FM personnel, Environmental Health Services (EHS) personnel, the Administrator-on-Call (AOC), Infection Control Officer, and Operating Room Staff were notified.
10. Once on the scene the secondary response team is briefed on the situation.
11. The secondary response team further assesses the situation for the actions to take within the clinical operations and to help evaluate the needed repairs. (11A) They determined that surgeries scheduled for the effected spaces would have to be moved, the supply room taken offline, and the two effected emergency room bed bays temporarily closed. (11B) In limiting the services

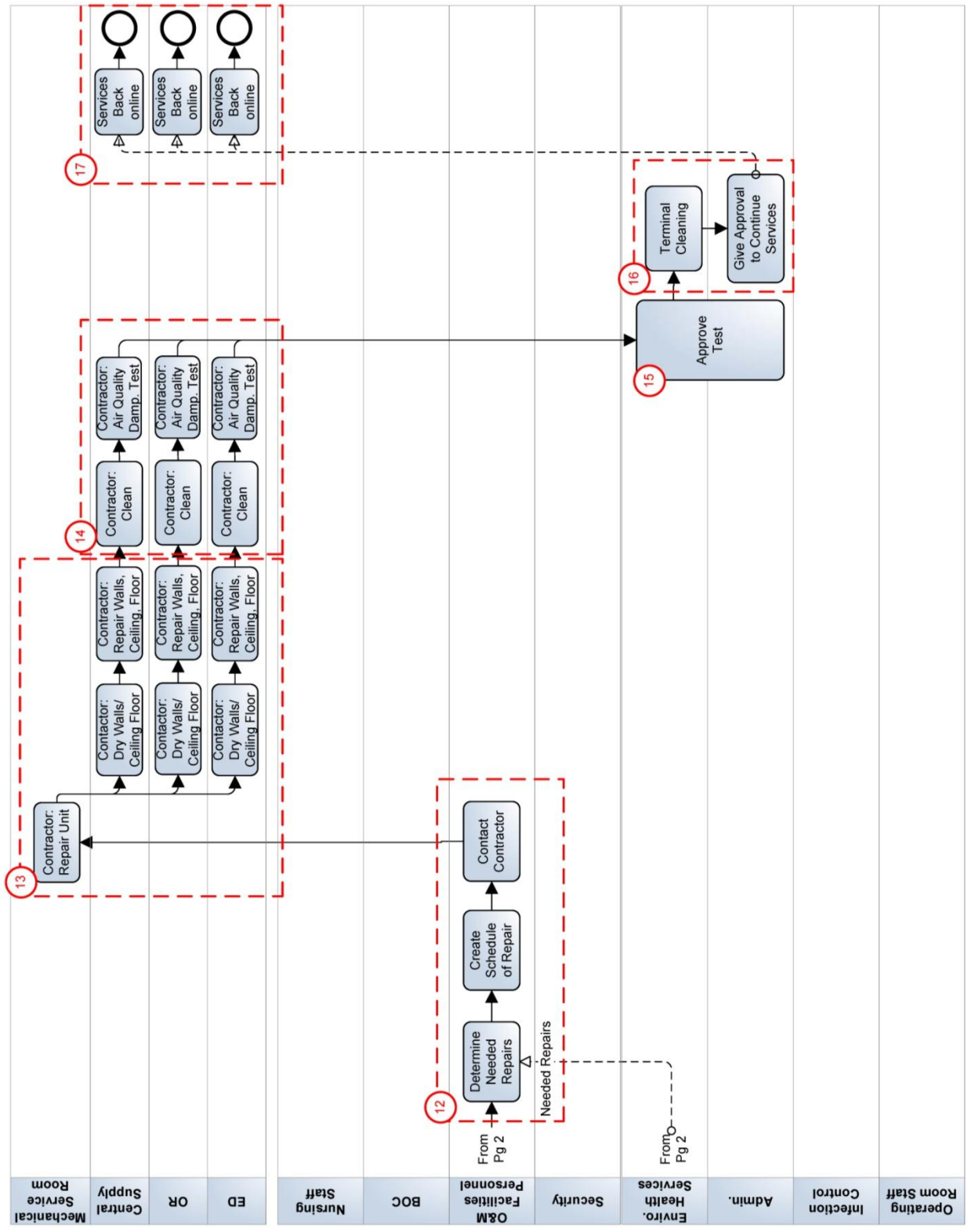
administration also notified other area hospitals of the limitation in capacity to make sure they would be able to take any overflow or critical case that affected hospital may not be able to handle during repairs.

12. FM personnel create a schedule for the repairs, which is approved by administration, and then contact contractors to complete the work that will not be done in house.
13. The contractor comes to repair the unit, dry walls, ceilings, and floors in the affected areas, and conduct the need repairs to the walls, ceilings, and floors.
14. When the repairs are completed the contractor cleans the spaces and conducts air quality and material dampness testing to make sure environmental conditions meet healthcare regulations.
15. Environmental health services and hospital administration review and approve the test results.
16. After test results are reviewed and approved, environmental health services conducts a terminal cleaning of the areas and administration gives the final approve to continue clinical operations in the affected areas.
17. Once administration gives the approval the services are put back online.

Steps 13 – 17 occur separately but concurrently for the effected spaces of the Central Supply, Operating Rooms, and Emergency Department Bays that had water incursion damage.


Mechanic Unit Malfunction – Water Incursion in OR – Page 1
Mechanical Service Room
Central Supply
OR
ED
Nursing Staff
BOC
O&M Facilities Personnel
Security
Enviro. Health Services
Admin.
Infection Control
Operating Room Staff
Malfunctioned Air Handler Unit
Leaked Water Appears
Noticed water incursion by staff
Call Report
1
Notifies BOC of Problem
Receive Notice of Problem
2
Log Call and Dispatch Mechanic
Create Work-order Report
Mechanic: Receive Dispatch
Go to Scene
3
Update Work Order
Contain Problem and Report to BOC Operator
4
Locate source of Problem
Limit Damage (shut down source)
5
Dispatch Additional Personnel
6
Dispatch Orders
Receive Dispatch Nursing House Manager
Receive Dispatch – Additional Personnel
Receive Dispatch
Receive Dispatch Charge Person
Cont. Pg 2
Cont. Pg 2
Cont. Pg 2
Cont. Pg 2


Mechanical Unit Malfunction – Water Incursion in OR – Page 2
Mechanical Service Room
Central Supply
OR
ED
Nursing Staff
BOC
O&M Facilities Personnel
Security
Enviro. Health Services
Admin.
Infection Control
Operating Room Staff
From Pg 1
Confer and Determine Level
Confer and Determine Threat Levels
Confer for determination of Situation and Determine location/infection risk Area Criteria and Risk/Damage Incident Level
Report Level & Situation to BOC
Receive Report
Dispatch Relevant Personnel
Give Brief on Situation
Receive Dispatch Additional Personnel
Director of Safety: Receive Dispatch
Receive Dispatch (AOC)
Receive Dispatch
Arrive at Scene
Receive Briefing
Assess Situation
Notify Area Hospitals
Postpone Surgery
Determine Extent of Repair Needed to Become Operational
To Pg 3

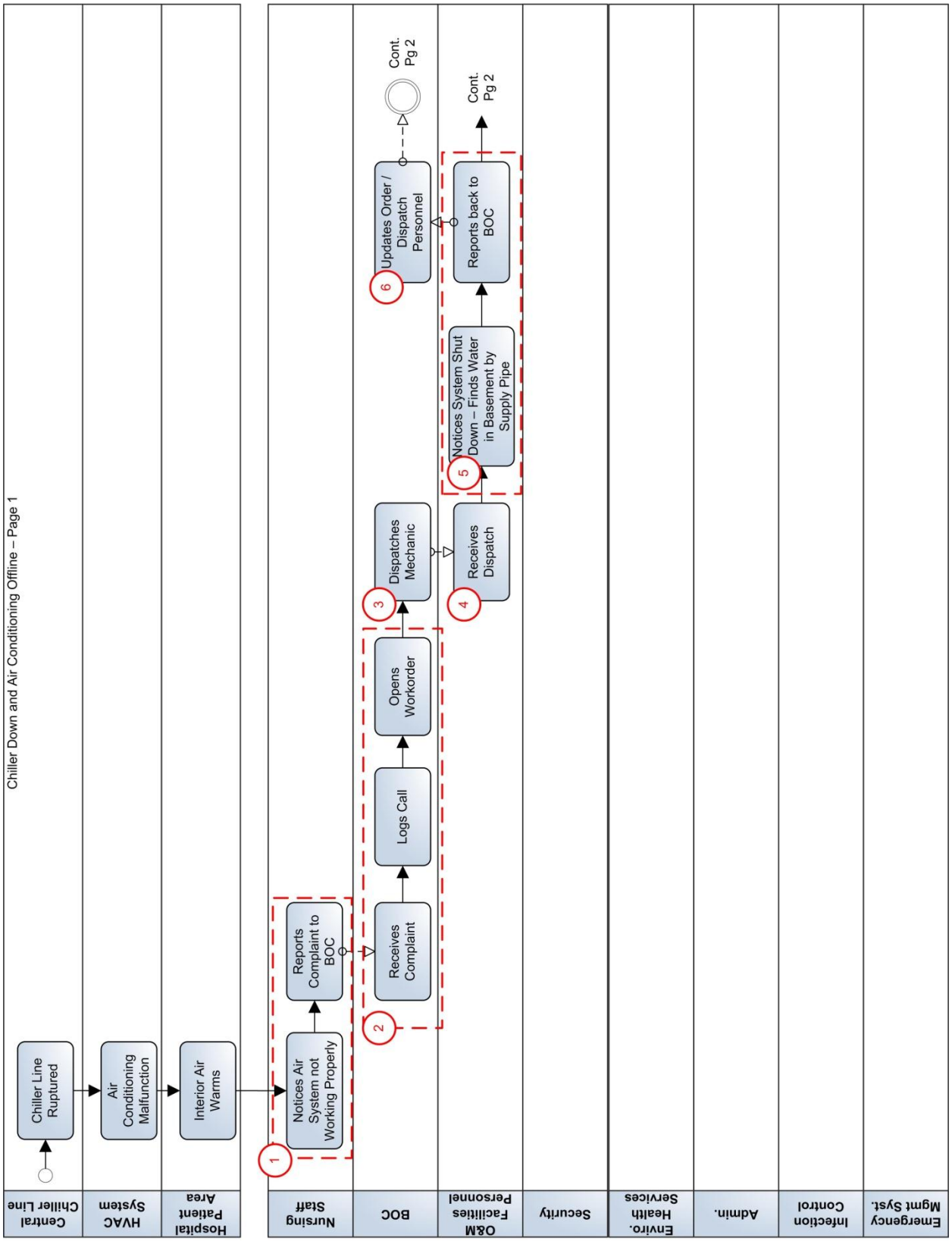

Operating Room Staff
Infection Control
Admin.
Envirо. Health Services
Security
O&M Facilities Personnel
BOC
Nursing Staff
ED
OR
Central Supply
Mechanical Service Room
From Pg 2
From Pg 2
Determine Needed Repairs
Create Schedule of Repair
Contact Contractor
Needed Repairs
Contractor: Repair Unit
Contactor: Dry Walls/ Ceiling Floor
Contactor: Repair Walls, Ceiling, Floor
Contractor: Clean
Contractor: Air Quality Damp. Test
Approve Test
Terminal Cleaning
Give Approval to Continue Services
Services Back online
12
13
14
15
16
17

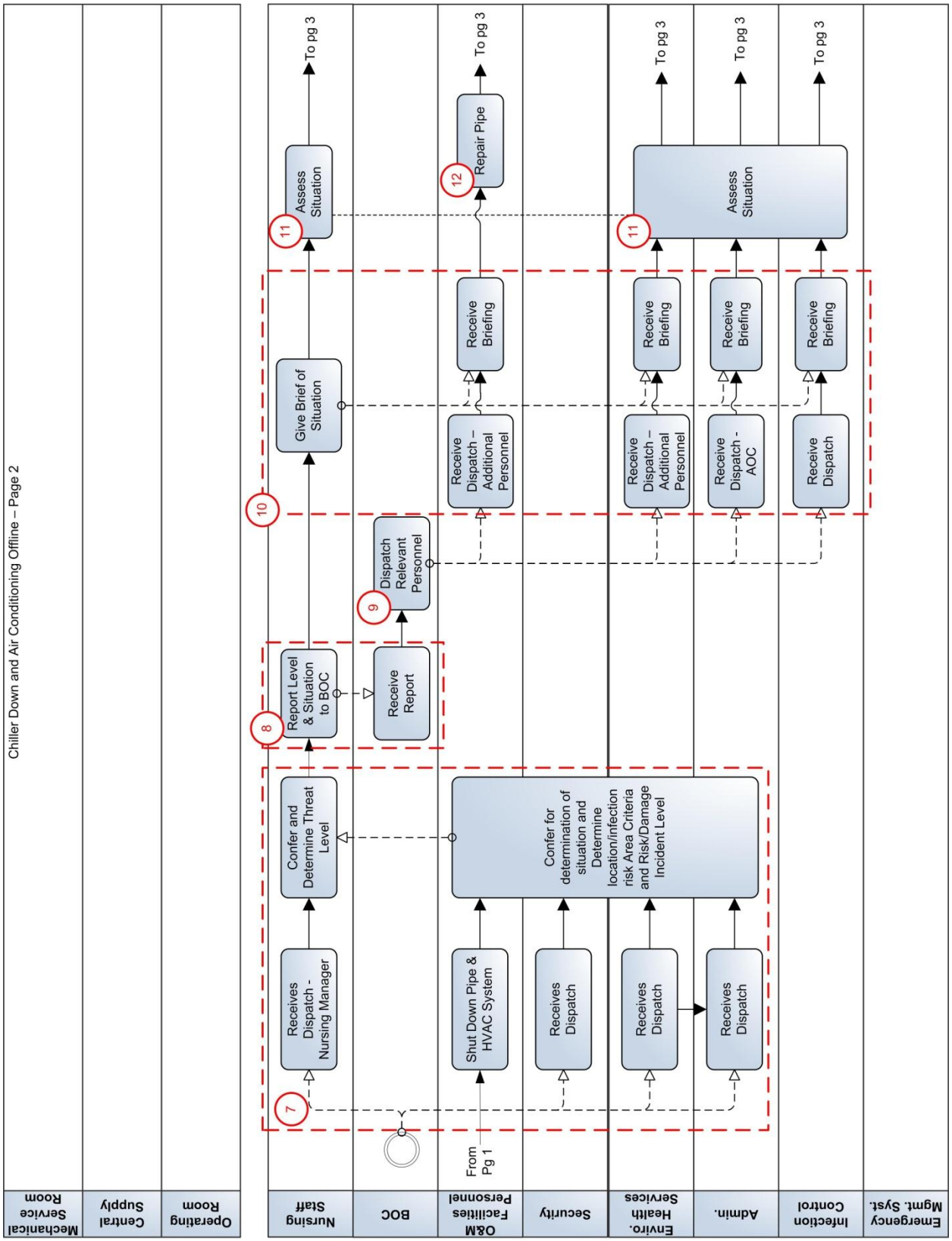
Appendix E: Case Study 2 – Process Model

This appendix is referenced in section 3.3 of the document and contains the process model that is used for Case Study 2. The process model is documented in Business Process Model Notation (BPMN) with the use of swim lanes representing the different actors (personnel) involved in the process. The step by step numbered narrative represents the numbers on the three separate pages of the Case Study 2 BPMN. These steps are a broken down representation of the separate tasks that took place during the event described in full narrative in Section 3.3 *Case Narrative*.

1. Nursing staff notices an uncomfortable rise in temperature throughout the unit and report to the building call center that there is a problem with the temperature.
2. The operator at the call center receives and logs the call and then opens a word order.
3. The operator sends dispatch information to the mechanic on duty.
4. The mechanic receives the dispatch and reports to the area where the complaint was issued to troubleshoot the problem.
5. The mechanic notices that the system is shut down. Upon checking other units on the floor, he traces systems back to the mechanical room in the basement of the building where he finds water flowing from the supply pipe. He reports the findings back to the call center.
6. Upon receiving the report the operator dispatches an initial response team according to the emergency operation plan and protocol and updates the work order.
7. The initial response team receives the dispatch, arrive at the scene, do an initial scene assessment, and determine the threat levels and course of action.
8. The Nursing Manager reports the situation and response level to the Operator at the control center.
9. The control center Operator dispatches additional needed personnel.
10. The additional personnel receive the dispatch with the required information, report to the scene, and receive a briefing from the Nursing Manager.
11. Various administrative personnel assess the situation to see what needs to be done and what actions need to be taken.
12. FM staff contains the damage and begin the process to repair the broken pipe.
13. Hospital Administration and Nursing Staff decide to evacuate the facility based on the timeline for the repair. At this point it is approaching upper 80 F temperatures inside and is dangerous for the patients.
14. Nursing staff prepares to move the patients.
15. Administrators coordinate with local EMS agencies and hospitals to move patients.

16. Administrators cancel all scheduled procedures and begin to notify patients.
17. Nursing staff discharges patients that were ready to leave and helps move other patients with EMS agencies.
18. The patients, and their records, are relocated to other facilities.
19. FM personnel oversee the repair of the HVAC supply pipe. Their mechanics and 3rd party contractors are involved in the repairs.
20. FM goes through the process of hiring contractors to make the appropriate repairs to the walls that were damaged while starting to re-cool the building.
21. Administrative and clinical personnel determine the extent of damage on the floors and in clinical spaces and determine the extent of repairs.
22. FM oversees the cleaning, sanitization and repair of the patient floors.
23. FM oversees air quality testing to make sure that no mold, mildew, or other airborne contaminants are present after the work is complete and the initial cleaning of the affected areas.
24. FM oversees the terminal cleaning once the air quality test results are returned with acceptable results.
25. The spaces are turned over to clinical personnel, where the administration gives the final approval to bring back the patients and continue performing procedures.


Chiller Down and Air Conditioning Offline – Page 1
Central Chiller Line
HVAC System
Hospital Patient Area
Nursing Staff
BOC
O&M Facilities Personnel
Security
Enviro. Health Services
Admin.
Infection Control
Emergency Mgmt Syst.
Chiller Line Ruptured
Air Conditioning Malfunction
Interior Air Warms
Notices Air System not Working Properly
Reports Complaint to BOC
Receives Complaint
Logs Call
Opens Workorder
Dispatches Mechanic
Receives Dispatch
Notices System Shut Down – Finds Water in Basement by Supply Pipe
Reports back to BOC
Updates Order / Dispatch Personnel
Cont. Pg 2
Cont. Pg 2
1
2
3
4
5
6


Chiller Down and Air Conditioning Offline – Page 2
Mechanical Service Room
Central Supply
Operating Room
Nursing Staff
BOC
O&M Facilities Personnel
Security
Enviro. Health Services
Admin.
Infection Control
Emergency Mgmt. Syst.
From Pg 1
Receives Dispatch - Nursing Manager
Confer and Determine Threat Level
Report Level & Situation to BOC
Receive Report
Dispatch Relevant Personnel
Shut Down Pipe & HVAC System
Receives Dispatch
Confer for determination of situation and Determine location/infection risk Area Criteria and Risk/Damage Incident Level
Receives Dispatch
Receives Dispatch
Receives Dispatch
Give Brief of Situation
Assess Situation
Receive Dispatch – Additional Personnel
Receive Briefing
Repair Pipe
Receive Dispatch – Additional Personnel
Receive Briefing
Receive Dispatch - AOC
Receive Briefing
Assess Situation
Receive Dispatch
Receive Briefing
Assess Situation
To pg 3
To pg 3
To pg 3
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7
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10
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12
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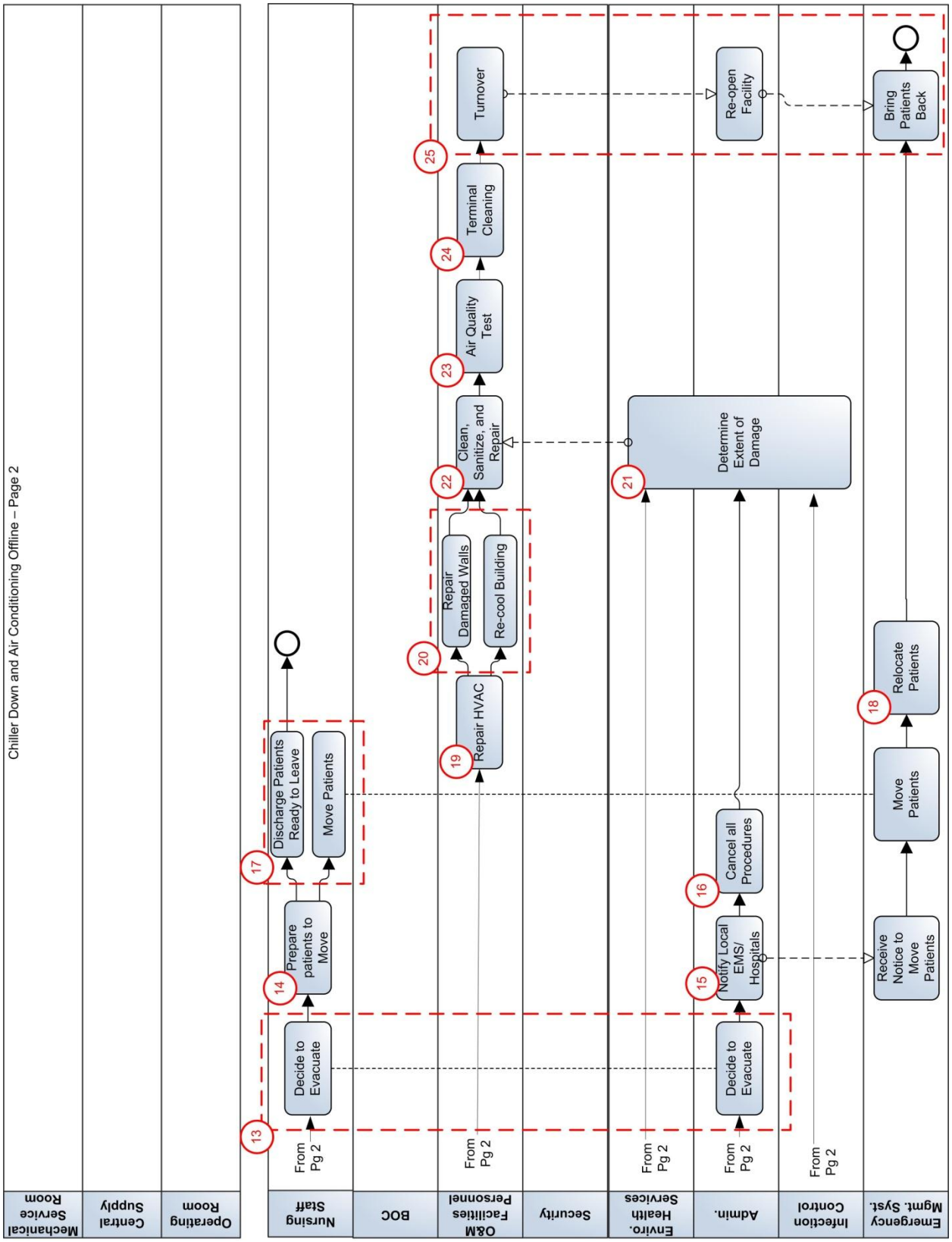

Chiller Down and Air Conditioning Offline – Page 2
Mechanical Service Room
Central Supply
Operating Room
Nursing Staff
BOC
O&M Facilities Personnel
Security
Enviro. Health Services
Admin.
Infection Control
Emergency Mgmt. Syst.
From Pg 2
Decide to Evacuate
Prepare patients to Move
Discharge Patients Ready to Leave
Move Patients
Repair HVAC
Repair Damaged Walls
Re-cool Building
Clean, Sanitize, and Repair
Air Quality Test
Terminal Cleaning
Turnover
Determine Extent of Damage
Notify Local EMS/ Hospitals
Cancel all Procedures
Re-open Facility
Receive Notice to Move Patients
Move Patients
Relocate Patients
Bring Patients Back
13
14
15
16
17
18
19
20
21
22
23
24
25

Appendix F: Case Study 1 – Health FMEA

This Appendix is referenced from Section 3.2 and contains the Failure Modes and Effects Analysis (FMEA) that was completed on Case Study 1. This analysis is summarized within the journal paper in Section 3.1 and presented in this appendix with the entire analysis description and FMEA table.

The analysis is completed with the scope of looking at the air handler / HVAC system located over the operating rooms suite in terms of malfunction and effects on environmental quality, patient safety risk, and disruption to facility services. Figure 1 contains a functional block diagram of the system. The air handler supplies the operating suite. Parts of the system that are included are the chiller, chiller supply lines, and operating room. Figure 2 shows a functional block diagram of the system component "Air Handler".

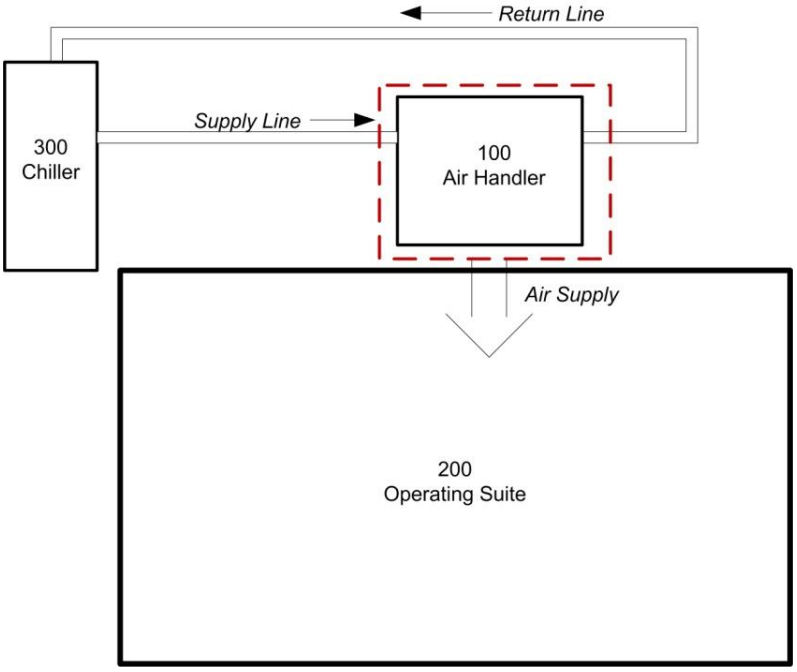


Figure 1: Functional Block Diagram of System

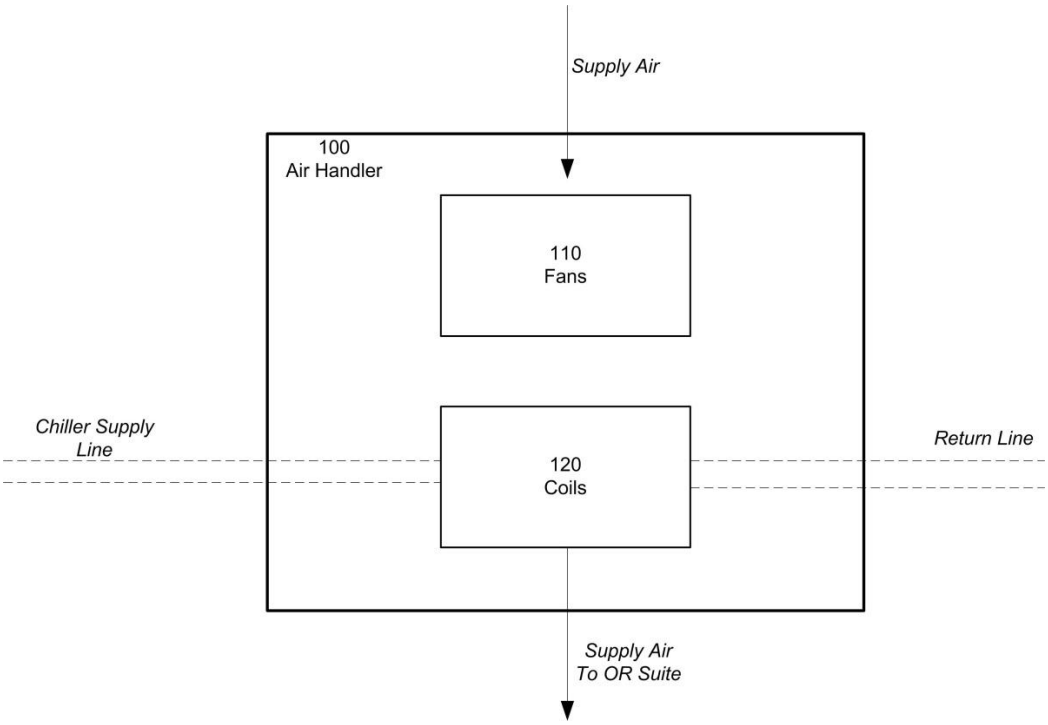


Figure 2: Function Block Diagram of System Component “Air Handler”

Failure Modes and Effects Analysis (FMEA) - Patient Safety

Mechanical System over Operating Room Suite

Item Number	Item	Potential Failure Mode	Failure Cause	Facility Failure Effects	Health Failure effects	Likelihood of Occurrence	Detection Method	Likelihood of Detection	Severity	Actions to Reduce Occurrence of Failure
100.01	HVAC Air handler	Chiller supply line leak over Janitor closet	leak at fitting/oxidation and pin hole leak form	water in ceiling material of closet/fix and replace ceiling	Airborne contaminates and mold/mildew	Medium	flow sensor or visual water mark on ceiling	Medium	Low	Regular maintenance of systems
100.02		Chiller supply line leak over non-sterile corridor	leak at fitting/oxidation and pin hole leak form	water in ceiling material needs to be dried/replaced	Airborne contaminates and mold/mildew - Respiratory problems to patients or other infections	Medium	flow sensor or visual water mark on ceiling	High	Medium	Regular maintenance of systems and training to report cases as soon as something is noticed
100.03		Chiller supply line leak over sterile supply	leak at fitting/oxidation and pin hole leak form	water in ceiling, supplies need to be moved - replaced	Airborne contaminates and mold/mildew in ceiling - possible contamination of supplies	Medium	flow sensor or visual water mark on ceiling	Medium	High	Regular maintenance of systems and training to report cases as soon as something is noticed
100.04		Chiller supply line leak over unoccupied OR room	leak at fitting/oxidation and pin hole leak form	close OR for repair	Airborne contaminates - threat to patients if not resolved and contained	Medium	flow sensor, visual water mark on ceiling or negative air quality test	High	High	Regular maintenance of systems and training to report cases as soon as something is noticed
100.05		Chiller supply line leak over prepped OR room	leak at fitting/oxidation and pin hole leak form	close OR and move surgery to another room	Airborne contaminates - threat to patients if not resolved and contained	Medium	flow sensor, visual water mark on ceiling or negative air quality test	High	High	Regular maintenance of systems and training to report cases as soon as something is noticed

Item Number	Item	Potential Failure Mode	Failure Cause	Facility Failure Effects	Health Failure effects	Likelihood of Occurrence	Detection Method	Likelihood of Detection	Severity	Actions to Reduce Occurrence of Failure
100.06		Chiller supply line leak over occupied OR room	leak at fitting/oxidation and pin hole leak form	drape patient and finish surgery	Patient acquires infection	Medium	flow sensor, visual water mark on ceiling or negative air quality test	High	High	Visually inspect room before starting for signs of potential problems or issues that may be present
100.07		Broken chiller pipe over OR suite - system shut down	leak at disconnected fitting	close location, contain water, stop leak, and clean up - finish OR's in progress in unaffected rooms	Patient acquires infection	Medium	HVAC or flow sensor, visual notice of flowing water	High	HIgh	Visually inspect room before starting for signs of potential problems or issues that may be present
110.01	Chiller coil in air handler unit	coil blocked and backflow leak over janitor closet	leak from blocked coil in unit	water on ceiling and floor	Staff slip and injury, supplies damaged or contaminated extend to patient infection	Medium	HVAC sensor, visual notice of water dripping from ceiling	Medium	High	Regular maintenance of systems and training to report cases as soon as something is noticed
110.02		coil blocked and backflow leak over non-sterile corridor	leak from blocked coil in unit	water in ceiling material needs to be dried/replaced	Airborne contaminates and mold/mildew - Respiratory problems to patients or other infections	Medium	flow sensor or visual water mark on ceiling	High	Medium	Regular maintenance of systems and training to report cases as soon as something is noticed
110.03		coil blocked and backflow leak over sterile storage	leak from blocked coil in unit	water in ceiling, supplies need to be moved	Airborne contaminates and mold/mildew in ceiling - possible contamination of supplies	Medium	flow sensor or visual water mark on ceiling	Medium	High	Regular maintenance of systems and training to report cases as soon as something is noticed

Item Number	Item	Potential Failure Mode	Failure Cause	Facility Failure Effects	Health Failure effects	Likelihood of Occurrence	Detection Method	Likelihood of Detection	Severity	Actions to Reduce Occurrence of Failure
110.04		coil blocked and backflow leak over unoccupied OR room	leak from blocked coil in unit	close OR for repair	Airborne contaminates - threat to patients if not resolved and contained	Medium	flow sensor, visual water mark on ceiling or negative air quality test	High	High	Regular maintenance of systems and training to report cases as soon as something is noticed
110.05		coil blocked and backflow leak over prepped OR room	leak from blocked coil in unit	close OR and move surgery to another room	Airborne contaminates - threat to patients if not resolved and contained	Medium	flow sensor, visual water mark on ceiling or negative air quality test	High	High	Regular maintenance of systems and training to report cases as soon as something is noticed
110.06		coil blocked and backflow leak over occupied OR room	leak from blocked coil in unit	drape patient and finish surgery	Patient acquires infection	Medium	flow sensor, visual water mark on ceiling or negative air quality test	High	High	Visually inspect room before starting for signs of potential problems or issues that may be present
110.07		condensate drain blocked over janitor closet	evaporation tray overflows	water mark on ceiling	contaminated supplies -potential risk of infection	Medium	Visual notice - or moisture sensor	Medium	High	Regular maintenance of systems and training to report cases as soon as something is noticed
110.08		condensate drain blocked over non-sterile corridor	evaporation tray overflows	water in ceiling material needs to be dried/replaced	Airborne contaminates and mold/mildew - Respiratory problems to patients or other infections	Medium	flow sensor or visual water mark on ceiling	High	Medium	Regular maintenance of systems and training to report cases as soon as something is noticed

Item Number	Item	Potential Failure Mode	Failure Cause	Facility Failure Effects	Health Failure effects	Likelihood of Occurrence	Detection Method	Likelihood of Detection	Severity	Actions to Reduce Occurrence of Failure
110.09		condensate drain blocked over sterile supply	evaporation tray overflows	water in ceiling, supplies need to be moved - replaced	Airborne contaminates and mold/mildew in ceiling - possible contamination of supplies	Medium	flow sensor or visual water mark on ceiling	Medium	High	Regular maintenance of systems and training to report cases as soon as something is noticed
110.10		condensate drain blocked over unoccupied OR room	evaporation tray overflows	close OR for repair	Airborne contaminates - threat to patients if not resolved and contained	Medium	flow sensor, visual water mark on ceiling or negative air quality test	High	High	Regular maintenance of systems and training to report cases as soon as something is noticed
110.11		condensate drain blocked over prepped OR room	evaporation tray overflows	close OR and move surgery to another room	Airborne contaminates - threat to patients if not resolved and contained	Medium	flow sensor, visual water mark on ceiling or negative air quality test	High	High	Regular maintenance of systems and training to report cases as soon as something is noticed
110.12		condensate drain blocked over occupied OR room	evaporation tray overflows	drape patient and finish surgery	Patient acquires infection	Medium	flow sensor, visual water mark on ceiling or negative air quality test	High	High	Visually inspect room before starting for signs of potential problems or issues that may be present
110.13		Water dripping from Coil over janitor closet	Improper Insulation Installed	water mark on ceiling	contaminated supplies -potential risk of infection	Medium	Visual notice - or moisture sensor	Medium	High	Regular maintenance of systems and training to report cases as soon as something is noticed

Item Number	Item	Potential Failure Mode	Failure Cause	Facility Failure Effects	Health Failure effects	Likelihood of Occurrence	Detection Method	Likelihood of Detection	Severity	Actions to Reduce Occurrence of Failure
110.14			Dirt on coil	water mark on ceiling	contaminated supplies -potential risk of infection	Medium	Visual notice - or moisture sensor	Medium	High	Regular maintenance of systems and training to report cases as soon as something is noticed
110.15		Water dripping from coil over non-sterile corridor	Improper Insulation Installed	water mark on ceiling	contaminated supplies -potential risk of infection	Medium	Visual notice - or moisture sensor	Medium	High	Regular maintenance of systems and training to report cases as soon as something is noticed
110.16			Dirt on coil	water in ceiling material needs to be dried/replaced	Airborne contaminates and mold/mildew - Respiratory problems to patients or other infections	Medium	flow sensor or visual water mark on ceiling	High	Medium	Regular maintenance of systems and training to report cases as soon as something is noticed
110.17		Water dripping from coil over sterile supply	Improper Insulation Installed	water in ceiling, supplies need to be moved - replaced	Airborne contaminates and mold/mildew in ceiling - possible contamination of supplies	Medium	flow sensor or visual water mark on ceiling	Medium	High	Regular maintenance of systems and training to report cases as soon as something is noticed
110.18			Dirt on coil	water in ceiling, supplies need to be moved - replaced	Airborne contaminates and mold/mildew in ceiling - possible contamination of supplies	Medium	flow sensor or visual water mark on ceiling	Medium	High	Regular maintenance of systems and training to report cases as soon as something is noticed

Item Number	Item	Potential Failure Mode	Failure Cause	Facility Failure Effects	Health Failure effects	Likelihood of Occurrence	Detection Method	Likelihood of Detection	Severity	Actions to Reduce Occurrence of Failure
110.19		Water dripping from coil over unoccupied OR	Improper Insulation Installed	close OR for repair	Airborne contaminates - threat to patients if not resolved and contained	Medium	flow sensor, visual water mark on ceiling or negative air quality test	High	High	Regular maintenance of systems and training to report cases as soon as something is noticed
110.20			Dirt on coil	close OR for repair	Airborne contaminates - threat to patients if not resolved and contained	Medium	flow sensor, visual water mark on ceiling or negative air quality test	High	High	Regular maintenance of systems and training to report cases as soon as something is noticed
110.21		Water dripping from coil over prepped OR	Improper Insulation Installed	close OR and move surgery to another room	Airborne contaminates - threat to patients if not resolved and contained	Medium	flow sensor, visual water mark on ceiling or negative air quality test	High	High	Regular maintenance of systems and training to report cases as soon as something is noticed
110.22			Dirt on coil	close OR and move surgery to another room	Airborne contaminates - threat to patients if not resolved and contained	Medium	flow sensor, visual water mark on ceiling or negative air quality test	High	High	Regular maintenance of systems and training to report cases as soon as something is noticed
110.23		Water dripping from coil over occupied OR	Improper Insulation Installed	drape patient and finish surgery	Patient acquires infection	Medium	flow sensor, visual water mark on ceiling or negative air quality test	High	High	Visually inspect room before starting for signs of potential problems or issues that may be present
110.24			Dirt on coil	drape patient and finish surgery	Patient acquires infection	Medium	flow sensor, visual water mark on ceiling or negative air quality test	High	High	Visually inspect room before starting for signs of potential problems or issues that may be present

Appendix G: Case Study 2 – Health FMEA

This Appendix is referenced from Section 3.3 and contains the Failure Modes and Effects Analysis (FMEA) that was completed on Case Study 2. This analysis is summarized within the journal paper in Section 3.1 and presented in this appendix with the entire analysis description and FMEA table.

The analysis is completed with the scope of looking at the air conditioning system within a patient room area in terms of malfunction and effects on environmental quality, patient safety risk, and disruption to facility services.

Figure 1 contains a functional block diagram of the system. The chiller supplies the cold water to the air handler unit that provides tempered air to the patient room.

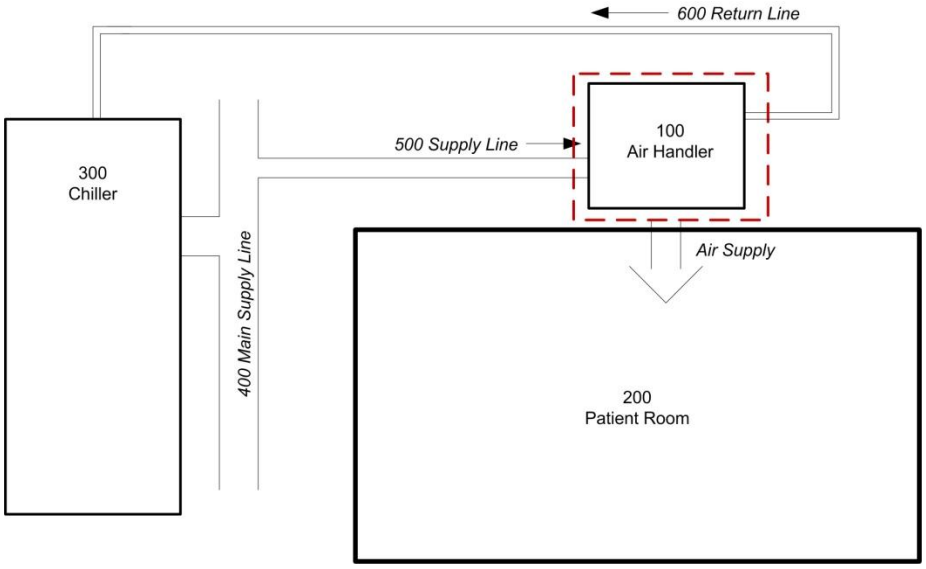


Figure 1: Functional Block Diagram of System

Figure 2 shows a functional block diagram of the system component “Air Handler”.

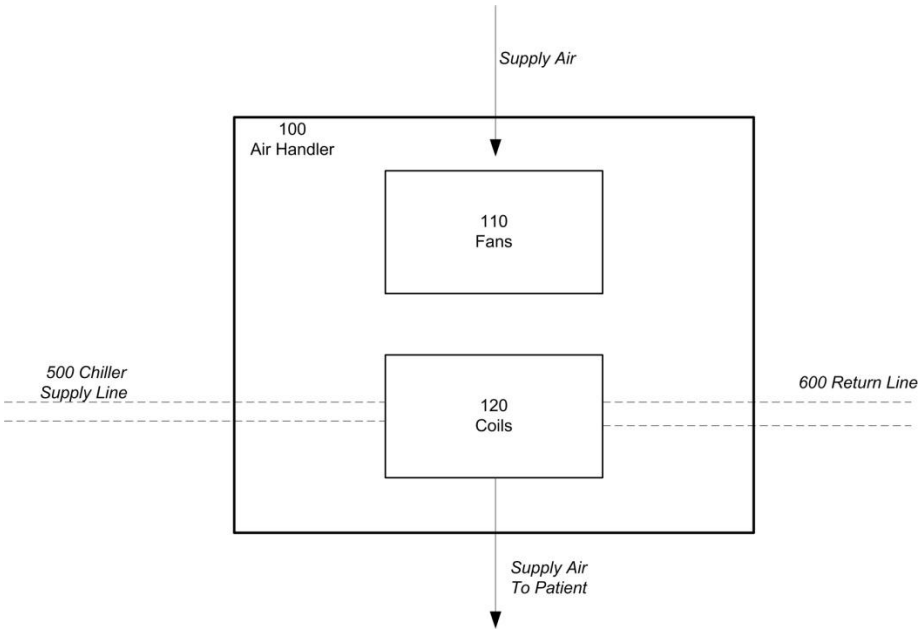


Figure 2: Function Block Diagram of System Component “Air Handler”

Failure Modes and Effects Analysis (FMEA) - Patient Safety

Air Conditioner over Patient Rooms

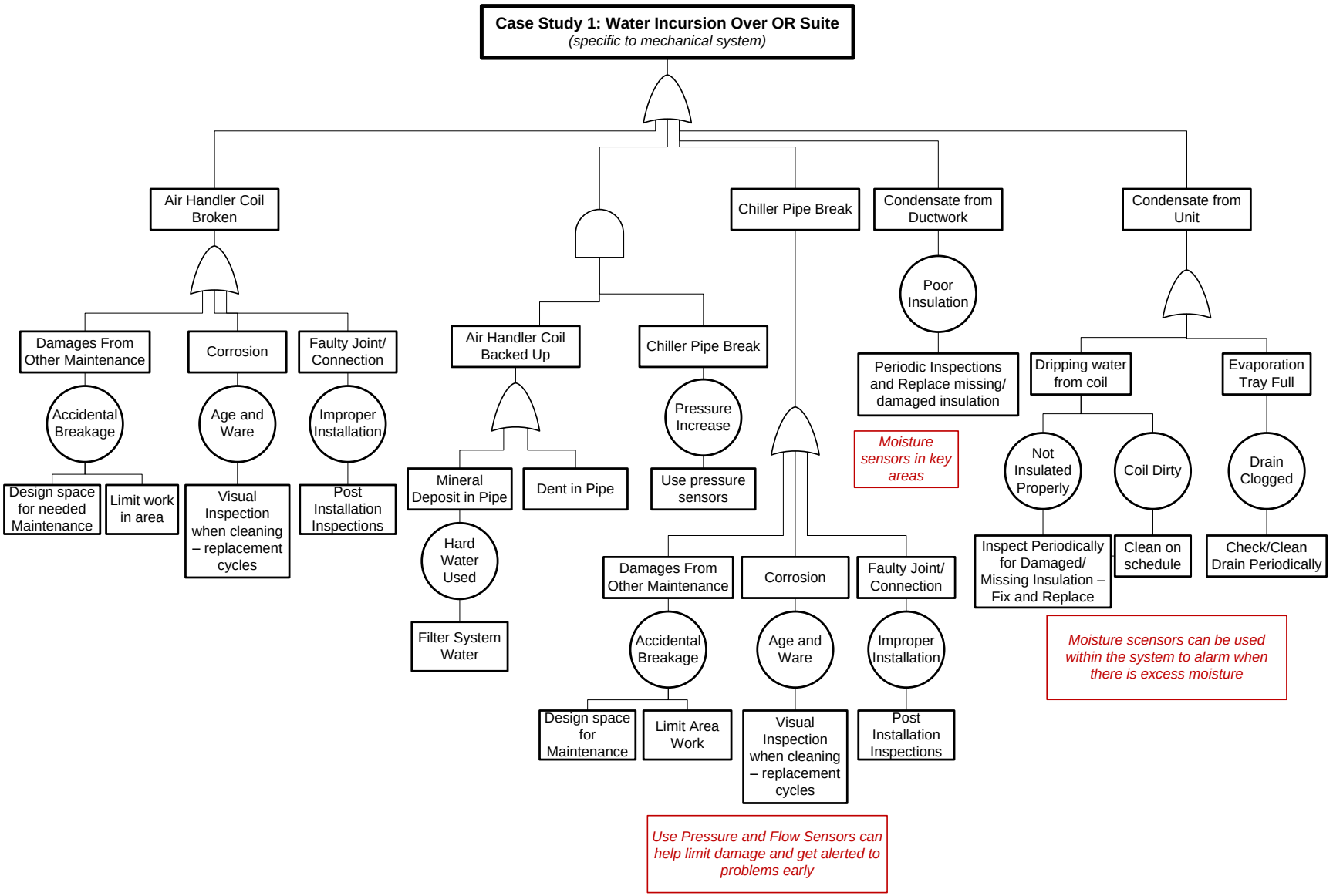
Item Number	Item	Potential Failure Mode	Failure Cause	Facility Failure Effects	Health Failure Effects	Likelihood of Occurance	Detection Method	Likelihood of Detection	Severity	Actions to Reduce Occurrence of Failure
110.01	air handler fan	fan does not circulate air	loss of electricity to the fan	air temperature and humidity may rise in the direct service area	Added heat and humidity can add discomfort	Medium	hvac sensor in building operation center	High	Medium	
110.02			fan motor overheats and stops working	air temperature and humidity rise	Added heat and humidity can add discomfort	Medium	hvac sensor in building operation center	High	Medium	Ensure proper and regular maintenance on unit to minimize possiblity of occurrence
110.03			loose (or warn) fan belts	air temperature and humidity rise	Added heat and humidity can add discomfort	Medium	hvac sensor - or complaint of warm room	High	Medium	Ensure proper and regular maintenance on unit to minimize possiblity of occurrence
110.04			loose electrical connection	air temperature and humidity rise	Added heat and humidity can add discomfort	Medium	hvac sensors - or complaint that room is warm	High	Medium	Ensure proper and regular maintenance on unit to minimize possiblity of occurrence
110.05			Faulty fan motor	air temperature and humidity rise	Added heat and humidity can add discomfort	Medium	hvac sensors - or complaint that room is warm	High	Medium	Ensure proper and regular maintenance on unit to minimize possiblity of occurrence
120.01	air handler coil	coil is not up to temperature	chiller water not entering coil	air temperature and humidity rise	Added heat and humidity can add discomfort	Medium	temperature sensor - complaint of room too hot	High	Medium	Ensure proper and regular maintenance on unit to minimize possiblity of occurrence

Item Number	Item	Potential Failure Mode	Failure Cause	Facility Failure Effects	Health Failure Effects	Likelihood of Occurance	Detection Method	Likelihood of Detection	Severity	Actions to Reduce Occurrence of Failure
120.02			blockage in coil due to mineral build-up	air temperature and humidty rise in room	Added heat and humidity can add discomfort	Medium	temperature sensor - complaint of room too hot	High	Medium	Ensure proper and regular maintenance on unit to minimize possiblity of occurrence
120.03		coil leaks	crack in pipe/joint not afixed properly	air temperature and humidity rise in room - water drips onto ceiling panel - temporarily controled by evaporation pan	Added heat and humidity can add discomfort - airborne particles with water/mold possible - possible extension to infection	Medium	temperature sensor - visually see water stain - complaint of room too hot	High	High	Ensure proper and regular maintenance on unit to minimize possiblity of occurrence
500.01	Secondary Chiller Line	break in secondary chiller line	crack in pipe - water released	air handler systems in zone stop working - temperature rises	Added heat and humidity can add discomfort - airborne particles with water/mold possible - possible extension to infection	Medium	complaints of temperature rising, temperature sensors, site of water	HIgh	High	Ensure proper and regular maintenance on unit to minimize possiblity of occurrence
400.01	Main Chiller Line	break in main chiller line	crack in pipe - water released	re-route line around break - regain HVAC before internal temperature rises	Added heat and humidity can add discomfort - airborne particles with water/mold possible - possible extension to infection	Medium	site of water in location of building - complaints of temperature rising - temperature sensors	High	High	Ensure proper and regular maintenance on unit to minimize possiblity of occurrence

Appendix H: Case Study 1 – Fault Tree Analysis

This appendix is referenced from Section 3.2 and contains the Fault Tree Analysis (FTA) that was completed during the analysis of Case Study 1. The FTA methodology and benefits are discussed in the journal paper in section 3.1.

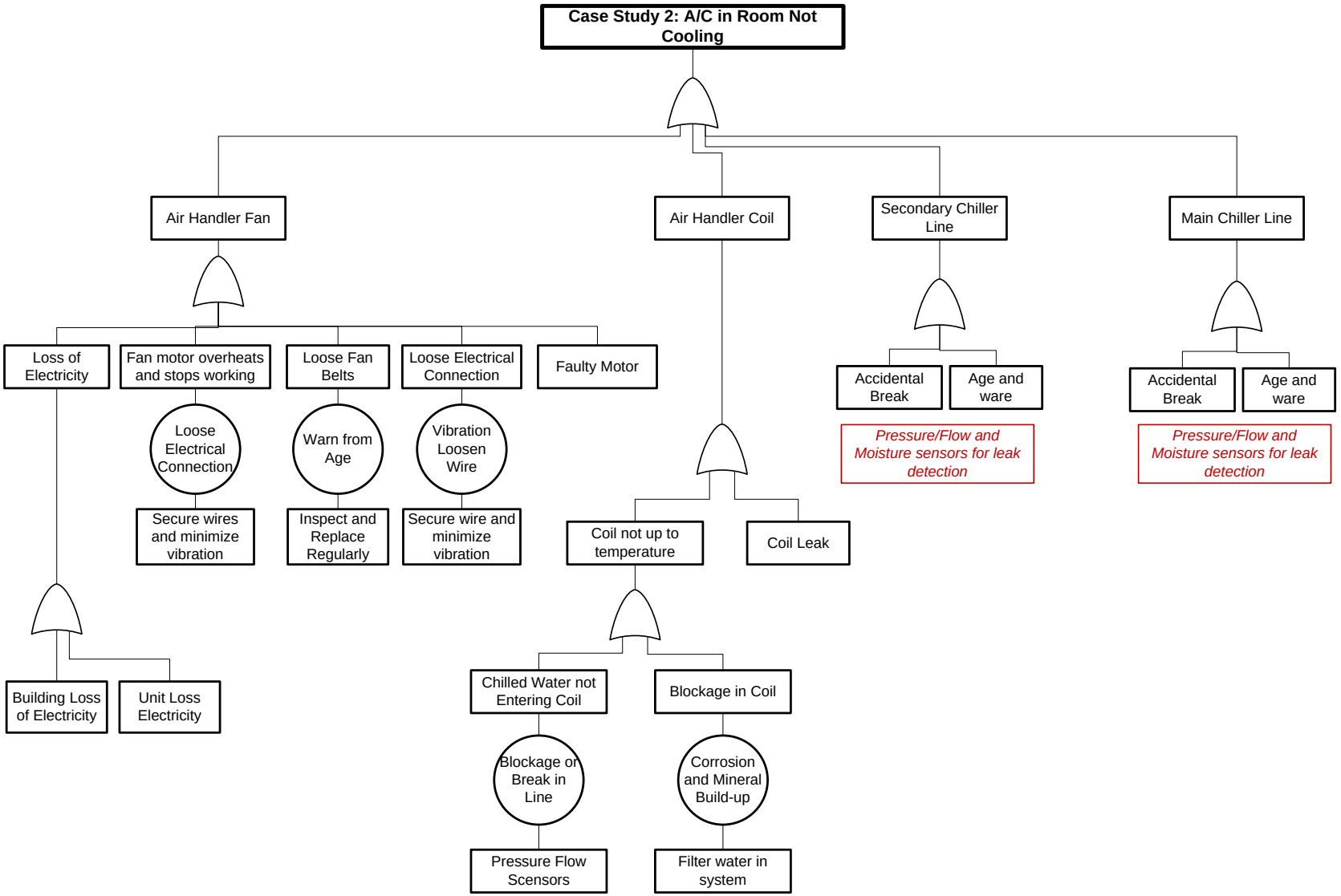
Fault Tree Analysis



Appendix I: Case Study 2 – Fault Tree Analysis

This appendix is referenced from Section 3.3 and contains the Fault Tree Analysis (FTA) that was completed during the analysis of Case Study 2. The FTA methodology and benefits are discussed in the journal paper in section 3.1.

Fault Tree Analysis

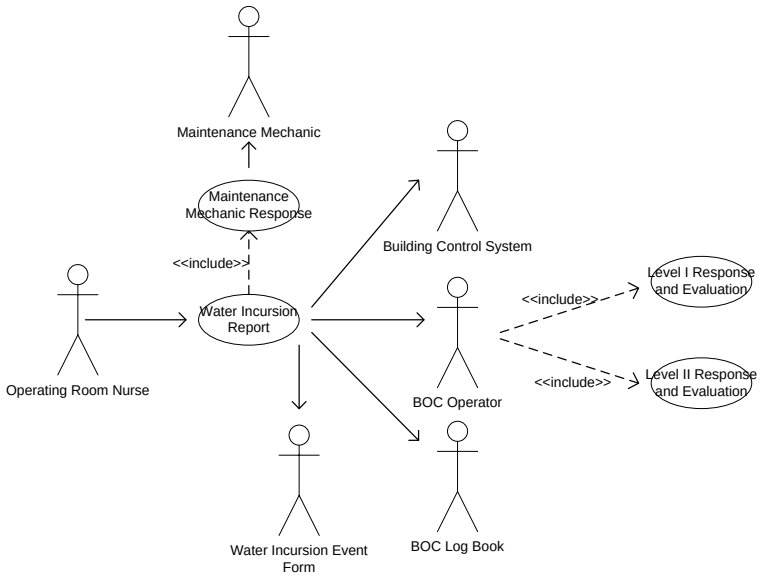


Appendix J: Case Study 1 – Use-cases and Analysis

This appendix is referenced from section 3.2 and contains the UML Use-case descriptions and diagrams that are part of the Case Study 1 analysis. This appendix contains the complete use-cases and the information tracking table that was used to analysis the information needs of each independent task within the use-case sequence. The reasoning behind the use of the UML Use-cases and how they were beneficial to the analysis and product model development is discussed in section 3.1.

Use-Case– 1. *Water Incursion Reported*

1. **Brief Description**
   This use-case describes the reporting by the Operating Room Nurse to BOC Operator of a water incursion event and the response taken by the Maintenance Mechanic and other facility staff and administration.
2. **Use-Case Diagram**



3. **Preconditions**
   - The Maintenance Mechanic and BOC Operator must possess a **radio**
   - The Operating Room Nurse and BOC Operator must possess a **phone**
   - The BOC Operator must have access to the **Building Control System** and it must be active and online.

4. **Basic Flow**
   {Water leaks from ceiling}

   1. The use-case begins when the Operating Room Nurse enters the sterile supply room to restock supplies and notices water dripping from the ceiling with a water mark down the wall and a pool of water on the floor.
   2. The Operating Room Nurse calls on the in-house phone to the BOC Operator with a water incursion report.
   3. The BOC Operator receives a call from the Operating Room Nurse about a water incursion.
   4. The BOC Operator creates a work order form in the Building Control System.
   5. The BOC Operator selects the type of work order as "Water Incursion Event"
   6. The Building Control System outputs a work order number for the BOC Operator.
      {Work-order Number Created}
   7. The BOC Operator logs the call in the BOC Log Book and records the name of the nurse, the type of problem, and work order number.
   8. The BOC Operator completes the Water Incursion Event form information that must be obtained from the initial contact which includes:
      a. What areas of the facility are involved? Building: Main Hospital, Department: (Surgery), Room Numbers : (sterile storage)

b. What is the room used for: OR storage.
c. When did the incursion occur: Day: Saturday Time: 2:00AM
d. Are any additional hazards involved?
e. Have additional hazards been eliminated?

9. The BOC Operator, by radio, dispatches the Maintenance Mechanic on duty. Include use-case ***Maintenance Mechanic Response***.
10. The BOC Operator gives the initial report information to the Maintenance Mechanic of facility, space, and use of space and what hazards should be expected.
11. The BOC Operator receives an update of the situation from the Maintenance Mechanic that there is standing water and the level I response team as well as additional facility operations personnel need to be dispatched to the scene.
12. The BOC Operator dispatches level I response team, by pagers with an emergency code. The Level I response team consists of Maintenance Mechanic, Security, Nursing House Manager, and Environmental Health Charge Person.
13. Include use-case ***Level 1 Response and Evaluation***.
14. The BOC Operator receives a call from the nursing house manager updating the situation after the Level 1 Response team conducts the Level 1 Response.
15. The BOC Operator logs the call and related work order number in the log book.
16. The BOC Operator then completes the Water Incursion Event form based on information from the level 1 response team. The form includes the following documented information by the BOC Operator:
    a. What is the extent of the damage? (material and how much is damaged) one operating suite, one sterile supply room, and two emergency room bays. Standing water in the sterile storage and water damage to walls, ceiling, and floor of all spaces. The zone supplying air to the operating suite needed to be shut down to contain damage.
    b. What was the source of the water? The chiller supply line of the Air Handler Unit.
    c. What caused the problem? The cooling coil within the air handler unit was blocked, causing an increase of pressure and the fitting to leak.
    d. Has the source of water been eliminated? The chiller supply line of the zone was shut off and the air handler shut down.
    e. What steps have been taken to clean the area? Environmental health services is vacuuming the water and starting to mop up the floor as the extent of damage is being evaluated.
    f. Has access to the area been restricted? Yes.
    g. Are patients/visitors been evacuated? There were no patients/visitors in the area at the time, the area has been restricted.
    h. Where are patients/visitors currently located?
    i. What is the Risk/Damage Level that has been assigned by the Level 1 Response Team? Level IV.
    j. Additional relevant information and related project numbers:
17. The BOC Operator dispatches the Level II response team, though a paging and code system, to the scene based on the threat level and location of the situation. The BOC Operator dispatches the facility operations director (or assistant) on call, director of safety, an environmental health services team to aid in clean-up, the administrator-on-call, infection control personnel, and clinical staff in charge for surgery and the emergency department.
18. Include use-case ***Level II Response and Evaluation***.
19. The BOC Operator receives a call from administration after completion of Level II Response.
20. The BOC Operator logs in contractors called by the Facility Operations Director to do the work.
21. The BOC Operator gives the contractors the correct keys to access the needed spaces.
22. Once the work is completed, the BOC Operator logs the contractors out and collects the keys.

5. Alternative Flows

Add flow sensor alarm

3a. A flow sensor alarm sounds in the BOC Control center.

.1 The BOC Operator responses to an alarm in the computerized automated control system.

.2 The BOC Operator reviews the alarm.

.3 The BOC Operator cross checks the alarm for work being done on the system in that location.

.4 The BOC Operator silences the alarm and pages the Maintenance Mechanic.

.5 Include use-case ***Check Alarm II***.

.5 The BOC Operator receives a call from the Maintenance Mechanic that it appears to be the coil in the air handler unit.

.6 The BOC Operator places a work order in the Building Control System for the Mechanical Shop to fix the problem.

.7 Include use-case ***Schedule and Repair***.

.8 End use-case.

Extension: No Standing Water

2a: The Nurse notices a water stain beginning to form on the ceiling.

.1 The nurse calls the BOC Operator with the report of water on ceiling.

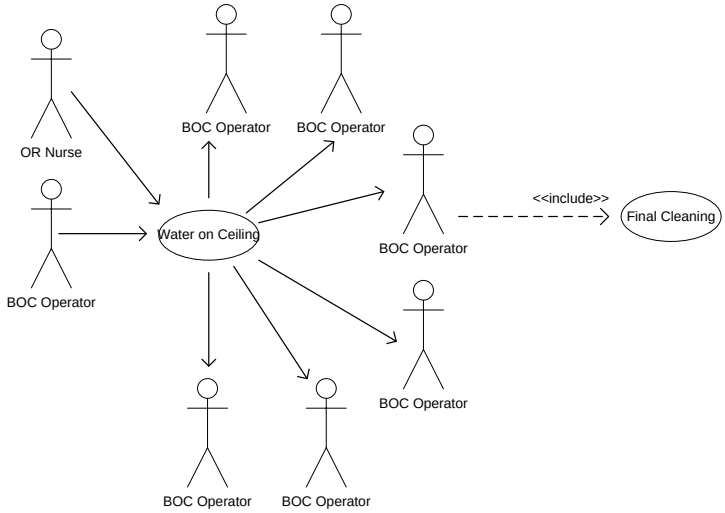
.2 Include use-case ***Water on Ceiling.***

Use-Case– 2. *Water on Ceiling*

1. Brief Description

This use-case describes the reporting of the operating room nurse of a water mark on the ceiling as opposed to standing water, in the sterile supply room. The required responses are different.

2. Use-Case Diagram



3. Preconditions

- The BOC Operator and Operating Room Nurse must have access to a phone.
- The BOC Operator must have access to the Building Control System and it be online.

4. Basic Flow

1. The BOC Operator receives a call from the Operating Room Nurse that there is a water mark appearing on the ceiling tile in the sterile supply room.
2. The BOC Operator creates a work order number from Building Control System and takes basic information from the nurse pertaining to the room, location of the leak and any other damages that are noticed.
3. The BOC Operator logs the call in the BOC Log Book and immediately pages the Maintenance Mechanic.
4. Include use-case ***Investigate Water Mark***.
5. The BOC Operator waits for a report back the Maintenance Mechanic.
6. The BOC Operator receives a call from the Maintenance Mechanic with an update.
7. The BOC Operator reports in the Work Order that the problem was an overflowing evaporation tray and the mechanic was able to empty the pan and clean out the condensation drain which was blocked with dust build-up.
8. The BOC Operator dispatches the Carpentry Shop to replace the damaged tiles.
9. The BOC Operator dispatches Environmental Health Services (EHS) to the scene to evaluate and do a ***Final Cleaning***.

5. Alternative Flow

Evaporation Tray Moisture Sensor:

1a. The BOC Operator responds to a Building Automation System Alarm caused by moisture.

.1 The BOC Operator checks for work being conducted in the area of the alarm.

.2 The BOC Operator pages the Maintenance Mechanic with the location and unit ID that are involved in the alarm.

.3 Include use-case ***Check Alarm I***.

.4 The BOC Operator waits for a call back from the Maintenance Mechanic for further action.

.5 The BOC Operator receives a call from the Maintenance Mechanic that water was building up in the evaporation tray.

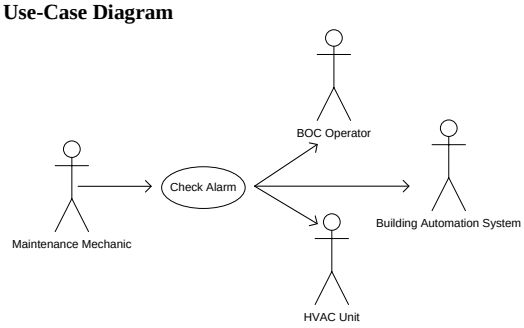
.6 The BOC Operator creates a work order to record the situation.

.7 The BOC Operator receives an update from the Maintenance Mechanic as to what was done to resolve the problem.

.8 The BOC Operator updates the work order with the information received from the Maintenance Mechanic and resets the alarm.

Use-Case– 3. *Check Alarm I*

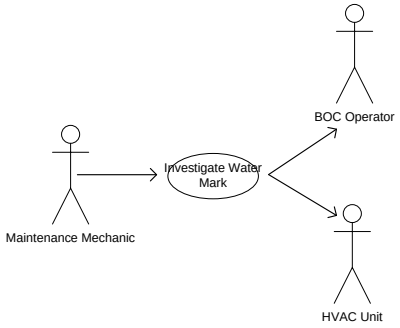
1. **Brief Description**
   This use-case describes the process taken for the Maintenance Mechanic responding to and diagnosing an alarm in the HVAC system.
2. **Use-Case Diagram**



3. **Preconditions**
   - BOC Operator has access to Building Automation System
   - Alarms come from Building Automation System
   - Mechanic and BOC Operator have pager system
   - Mechanic has access to house phone
4. **Basic Flow**
   1. The Maintenance Mechanic receives a page from the BOC Operator.
   2. The Maintenance Mechanic calls the BOC Operator for Alarm Information from the Building Automation System.
   3. The Maintenance Mechanic gets the alarm type, room/location, and unit ID to go check to see what the alarm is about.
   4. The Maintenance Mechanic goes to the mechanic floor above the operating suite.
   5. The Maintenance Mechanic locates the unit and sensor that had alarmed.
   6. The Maintenance Mechanic notices there is water in the evaporation tray.
   7. The Maintenance Mechanic calls the BOC Operator and lets him know an update of the situation and why the alarm went off.
   8. The Maintenance Mechanic empties the evaporation tray and then cleans the condensate drain.
   9. The Maintenance Mechanic then drips some water down the drain to see if it is clear.
   10. The Maintenance Mechanic updates the BOC Operator of what was done to resolve the problem and the alarm is reset.

Use-Case 4. – *Investigate Water Mark*

1. **Brief Description**
   This use-case describes the response and actions of the maintenance mechanic when he is called to investigate the water mark within the operating room suite.
2. **Use-Case Diagram**



3. **Preconditions**
   - The Maintenance Mechanic has access to the paging system.
   - The Maintenance Mechanic has access a house phone.

4. **Basic Flow**
    1. The Maintenance Mechanic receives a page of a water incursion investigation in the sterile supply of the operating suite from the BOC operator.
    2. The Maintenance Mechanic goes to the scene of the report.
    3. The Maintenance Mechanic checks to see that the water is not dripping through the ceiling to the floor.
    4. The Maintenance Mechanic goes to the stairwell to access the mechanical floor that services the operating room suites.
    5. The Maintenance Mechanic looks for possible causes over the area where the water was showing up.
    6. The Maintenance Mechanic notices water built up in the evaporation pan and that it is dripping over the edge to the ceiling below.
    7. The Maintenance Mechanic is able to drain the evaporation pan.
    8. The Maintenance Mechanic cleans out the condensate drain.
    9. The Maintenance Mechanic then notifies the BOC Operator of the cause of the problem.
5. **Alternative Flows**

6a. The Maintenance Mechanic notices water dripping from the HVAC unit but is unable to find the location of the water.

.1 The Maintenance Mechanic calls the BOC operator to dispatch the HVAC Mechanic

.2 BOC Operator creates work order for the Mechanical Shop

.3 BOC Operator dispatches the Mechanical Shop

.4 Include use-case ***Schedule and Repair***

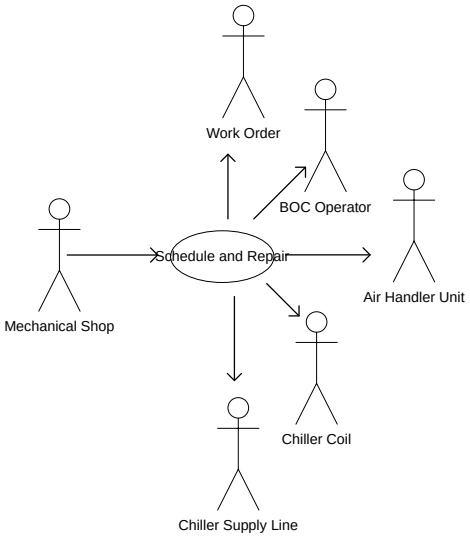
.5 end use-case

Use-Case 5 – *Schedule and Repair*

1. **Brief Description**

This use-case describes the process of the Mechanical Shop scheduling and making the repair of the broken HVAC Unit.

2. **Use-Case Diagram**



3. **Preconditions**
    - The Mechanical Shop has the necessary replacement equipment in stock to fix the HVAC unit Chiller Coil
4. **Basic Flow**
    1. The Mechanical Shop receives a Work Order requiring a replacement of an air handler coil from the BOC Operator.
    2. The Mechanical Shop checks with surgery staff to schedule the work in case if the Air Handler needs to be shut down for any period of time.
    3. The Mechanical Shop, during off hours (early in the morning), turns off the Chiller Supply Line to the Air Handler Unit.
    4. The Mechanical Shop removes the old Chiller Coil.
    5. The Mechanical Shop replaces the coil with the new Chiller Coil.
    6. The Mechanical Shop reattaches the Chiller Supply Line.
    7. The Mechanical Shop turns the Chiller Supply Line back on.
    8. The Mechanical Shop closes out the Work Order and notifies the BOC Operator

5. Alternative Flows

2.a. The chiller supply line requires an emergency repair.

.1 Mechanical Shop alerts surgery staff to immediate shut down of unit

.2 Surgical Administration moves surgery to open OR Suites.

.3 The Mechanical shop turns off the Chiller Supply Line to the Air Handler Unit

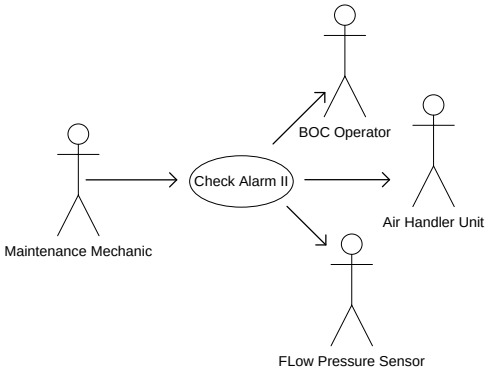
.4 Return to step 4.

Use-Case 6 – *Check Alarm II*

1. Brief Description

The use-case describes the process taken by the maintenance mechanic to check a flow pressure alarm.

2. Use-Case Diagram



3. Preconditions

- The Flow Pressure Sensors are connected to the Building Automation System.
- The BOC Operator has access to the Building Automation System.
- The Maintenance Mechanic and BOC Operator have access to the paging system.

4. Basic Flow

1. The Maintenance Mechanic receives a page from the BOC Operator of an alarm.
2. The Maintenance Mechanic calls the BOC Operator for status and location of alarm.
3. The Maintenance Mechanic arrives on scene.
4. The Maintenance Mechanic notices that there is no dripping water in the area of the Air Handler Unit and from the placement of the Flow Pressure Sensors, the most likely cause of the pressure change is the air handler unit coil.
5. The Maintenance Mechanic calls the BOC Operator to inform him of his diagnosis.

5. Alternative Flows

4.A The flow sensors are showing normal pressure

.1 The Maintenance Mechanic determines that everything looks correct.

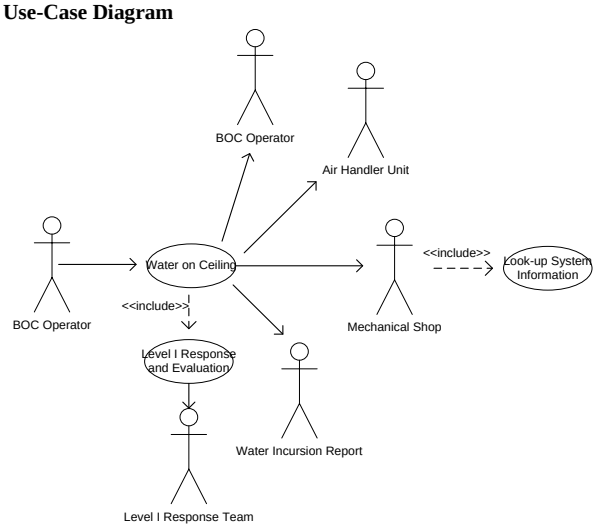
.2 The Maintenance Mechanic calls the BOC Operator to reset the alarm.

.3 The BOC Operator resets the alarm and documents the reasons.

.4 End use-case.

Use-Case 7– *Maintenance Mechanic Response*

1. **Brief Description**
   This use-case describes the Maintenance Mechanics Response to the Water Incursion Report
2. **Use-Case Diagram**



3. **Preconditions**
   - Maintenance Mechanic and BOC Operator have access to the radio.
   - Mechanical Shop has access to the radio.
   - Maintenance Mechanic knows location of storage closet and Mechanical Level Access.
4. **Basic Flow**
   1. Maintenance Mechanic receives dispatch call over the radio by the BOC Operator of reported water incursion. Included in the dispatch is the initial report information of location, use of space, and any hazards that should be prepared for.
   2. The Maintenance Mechanic goes to scene of Water Incursion Report.
   3. The Maintenance Mechanic quickly surveys the situation and notifies the BOC Operator to dispatch the Level I Response Team to the location.
   4. The Maintenance Mechanic goes to the storage closet on the floor and gets a Water Drum to put under the leak and some towels to lie on the floor to prevent water from spreading.
      {Contain Leak}
   5. The Maintenance Mechanic contains water dripping from ceiling and blockades water from traveling against the floor.
   6. The Maintenance Mechanic goes to the nearest Mechanical Floor Access stairway and unlocks the door to access the mechanical floor catwalk system.
   7. The Maintenance Mechanic looks for source of the water within the mechanic floor above the OR Suite and sterile storage where the water was coming through.
   8. The Maintenance Mechanic finds leak in Chiller Supply Line where it connects to an Air Handler Unit by noticing the water dripping from fitting through to the ceiling below.
   9. The Maintenance Mechanic calls the Mechanical Shop by two-way-radio to identify the extent of systems that need to be shut down, the back-up system plans, if any, and how to shut off the water.
   10. The Maintenance Mechanical Shop completes the process ***Looks up Systems Information***.
   11. Maintenance Mechanic receives a return two-way-radio call from the Mechanical Shop identifying the systems that need to be shut down and processes of shutting them down.
   12. The Maintenance Mechanic locates the shut-off valve by identifying the valve-ID given by the Mechanical Shop and shuts off the chiller water to the zone serving the effected unit.
   13. The Maintenance Mechanic then follows the information supplied by the Mechanical Shop as what precautions need to be taken to shut down the Air Handler Unit so it can then be diagnosed and repaired.
   14. The Maintenance Mechanic shuts down Air Handler unit by the procedures given to him by the Mechanical Shop.
   15. The Maintenance Mechanic notifies the BOC Operator of the details of situation including the preliminary cause identified, and what zones are affected.
   16. The BOC Operator goes through the process of ***Contact Clinical Administration***.
   17. Mechanic assists in response.
   18. Include use-case ***Level I Response and Evaluation***.
5. **Alternative Flows**
   9a: Mechanic looks up systems information from handle-held facility information devise.

.1 Mechanic looks up shut down information, including shut off valve location and procedures.

.2 Mechanic shuts off supply line to Air Handler

.3 Mechanic shuts off Air Handler, Return to step 15

Evaporation Tray Problem

3a: Mechanic arrives on scene to water stain on ceiling, no dripping water

.1 Mechanic goes to mechanic space above OR suite

.2 Mechanic locates the systems above the water mark

.3 Mechanic notices evaporation tray is overflowing with water

.4 Mechanic empties the evaporation tray

.5 Mechanic cleans the condensate drain from the evaporation tray

.6 Mechanic reports back to BOC source of problem

.7 Mechanic replaces damaged ceiling tile (or third party contractor repairs ceiling)

Evaporation Tray with Moisture Sensor

1a: Moisture sensor along evaporation tray alarms at BOC

.1 Mechanic is dispatched

.2 Mechanic goes to location of sensor

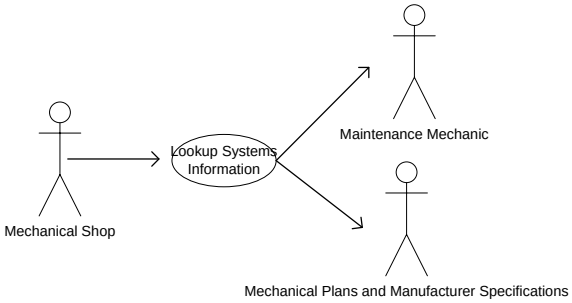
.3 Mechanic empties evaporation tray

.4 Mechanic cleans out condensate drain

.5 Mechanic reports back to BOC source of problem

Use-Case 8 – *Lookup Systems Information*

1. **Brief Description**
   This use-case describes the process between the Maintenance Mechanic and Mechanical Shop to Lookup Systems Information in support of the Maintenance Mechanic Response.
2. **Use-Case Diagram**



3. **Preconditions**
   - The Mechanical Shop has access to the Mechanical Drawings and Specifications.
   - The Mechanical Equipment is located and identified by a bar-code/ID tag
4. **Basic Flow**
   1. The Mechanical Shop receives a radio call for information from the Maintenance Mechanic.
   2. The Mechanical Shop looks up the plans and looks for the affected zone by identifying the unit number.
   3. The Mechanical Shop looks at the Mechanical Drawings and Manufacturer Specifications on how to shut down the effected system.
   4. The Mechanical Shop radios the Maintenance Mechanic with location of the proper shut-off; giving him the ID tag number to make sure that he is shutting off the correct valve.
   5. The Mechanical Shop gives the Maintenance Mechanic the information for shutting down the air handler unit so there is no further damage.

5. **Alternative Flows**

2a. Mechanical Shop access BIM Maintenance Model.

.1 Mechanical Shop queries model by ID number.

.2 Mechanical Shop reviews Manufacturer Specifications

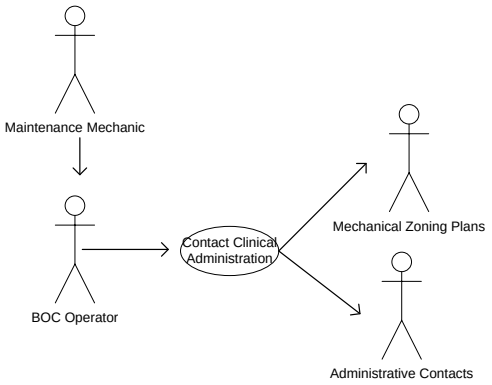
.3 Return to Step 4.

Use-Case 9 – *Contact Clinical Administration*

1. **Brief Description**

This use-case describes the process completed by the BOC Operator to contact Clinical Administration

2. **Use-Case Diagram**



3. **Preconditions**

- BOC Operator has access to Mechanical Zoning Plans to identify effected Zoning Area.
- BOC Operator has access to Emergency Contacts for the effected Zoning Area
- BOC Operator has listing of Administrative Contacts on duty and contact numbers

4. **Basic Flow**

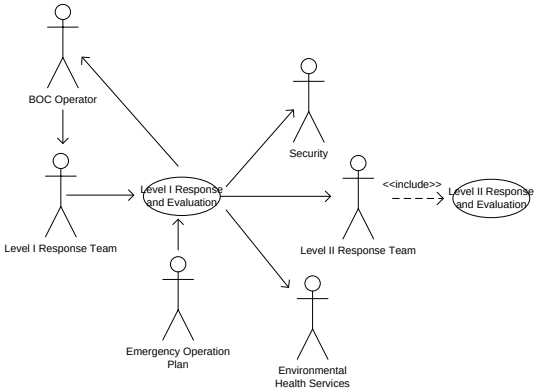
1. The BOC Operator receives a call from the Maintenance Mechanic about the HVAC System being shut down.
2. The BOC Operator looks up on the Zoning Plans, by unit ID, which Zoning Areas will be effected by the HVAC System being shut down.
3. The BOC Operator calls the Administration Contacts to notify them that one operating suite of 4 rooms will not have conditioned air and any surgery would have to be moved to the other functioning OR suites.

Use-Case 10 – *Level I Response and Evaluation*

1. **Brief Description**

This use-case describes the Level I Response Teams response and evaluation to the Water Incursion Report.

2. **Use-Case Diagram**

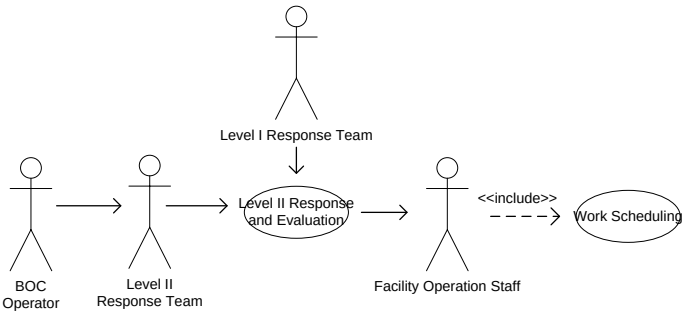


3. **Preconditions**
    - Level I response team has access to and is familiar with the Emergency Operation Plan, Location/Infection Risk Group Grid, Location/Infection Risk Area Criteria, and Risk/Damage Incident Level.
    - BOC Operator has listing of needed Level I Response Team members.
    - Level I Response Team and BOC Operator have access to paging system.

4. **Basic Flow**
    1. Level I Response Team responses to a page from the BOC Operator of a water incursion.
    2. Level I Response Team given the location and basic situation by the BOC Operator from the Water Incursion Resport.
    3. Level I Response Team arrives at scene to review the situation looking for extents of damage, areas that are damaged, any hazards, if the hazards can be resolved, and what should be done going forward.
    4. Level I Response Team, based on review of situation, determines the Location/Infection Risk Area Criteria and Risk/Damage Incident Level. The criteria for this determination is given in the Emergency Operation Plan under the Location/Infection Risk Group Grid. Based on the areas that the incident affected it is a "Highest Risk" situation. (The emergency department and supply and distribution would be of "High Risk", but since the Surgery/OR was involved, it was a "Highest Risk" situation.)
    5. The Level I Response Team also determined the "Extent of Damage Criteria for Response Team". {Because there was standing water on the floor that has reached the walls, and there were more than 10sq. ft. of drywall or ceiling involved, it was of "High" damage.}
    6. Using the two threat levels, the Risk/Damage Level was determined by the Level I Response Team as "Level IV".
    7. The Level I Response Team followed the immediate response actions as required by protocol to "Eliminate Safety Hazards" by containing further spread of water the best they could
    8. The Level I Response Team takes the action "Eliminate Water Source." This was completed by the Maintenance Mechanic with support of the Mechanical Shop in following procedures and protocol by the manufacturer and facility operators when he shut off the unit and supply pipe that were connected to the problem.
    9. The Level I Response Team takes the action "Make Contacts" by notifying the BOC of the levels, required response, and having the Level 2 Response Team Dispatched.
    10. The Level I Response Team did not need to take the action "Evacuate patients from affected spaces" as there were no ongoing surgeries within the operating suite at the time of the event and no patients in the effected emergency room bays.
    11. The Level I Response Team took the action "Vacuum standing water" by having the Environmental Health Services personnel go to the ground floor equipment supply closet and get a wet-vac.
    12. The Level I Response Team took the action "Control Access to the areas" by closing the emergency room bays that were affected and notifying surgery personnel to rearrange surgeries to use other operating suites, they notified OR Supply staff of the Sterile Supply room that needed repairs and would not be accessible.
    13. The Level I Response Team then waited for the Level 2 Response Team to respond to the area and conduct the ***Level II Response and Evaluation*** and give briefing on situation.

Use-Case 11 – *Level II Response and Evaluation*

1. **Brief Description**
   This use-case describes the response process of the Level II Response Team
2. **Use-Case Diagram**



3. **Preconditions**
    - The Level II Response Team and BOC Operator has access to the Paging system
    - The BOC Operator received the needed Team Members from the Level I Response Team.
    - The Level II Response Team has access to and is familiar with the Emergency Operation Plan.

4. Basic Flow

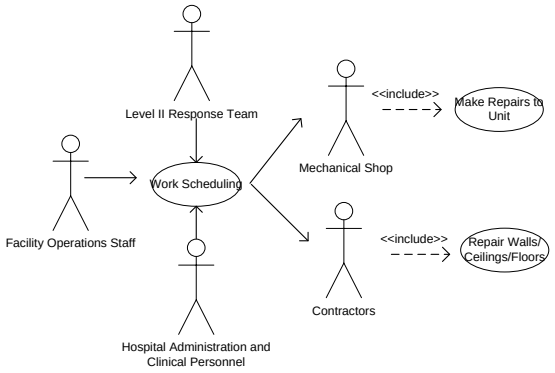
1. The Level II Response Team receives a coded page from the BOC Operator.
2. The Level II Response Team is given the location by the BOC Operator.
3. The Level II Response Team arrives on the scene.
4. The Level II Response Team receives the briefing from the Level I Response Team.
5. Administration and Operating Room Staff rearrange scheduled surgeries and notify area hospitals of limited resources.
6. The Level II Response Team examines the extent of damage.
7. The Level II Response Team determines repairs needed to become operational.
8. The Level II Response Team notifies Facility Operations Personnel of needed repairs.
9. Facility Operations Personnel complete the process of ***Work Scheduling***.

Use-Case 12 – *Work Scheduling*

1. Brief Description

This use-case describes the process taken by Facility Operations personnel to Schedule Work.

2. Use-Case Diagram



3. Preconditions

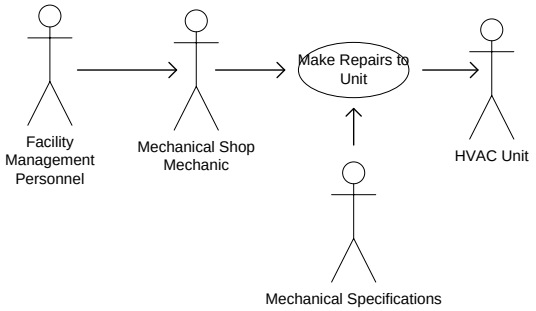
- Level II Response Team has knowledge of operational quality of healthcare facility.
- Contractors contacted for repairs are capable, knowledgeable, and available to do the work.

4. Basic Flow

1. Facility Operations Personnel review the damages.
2. Facility Operations Personnel receive list of needed repairs to become operations by Level II Response Team.
3. Facility Operations Personnel estimates the time for the repairs based on the wall and ceiling areas that need to be dried and replaced.
4. Facility Operations Personnel create a schedule for repairs and presents it to the Hospital Administration and Clinical Personnel of affected areas for approval.
5. Facility Operations Personnel receive approval of schedule.
6. Facility Operations contact the Mechanic Shop and Contractors needed to make the repairs.
7. Include use-case ***Make Repairs to Unit***.
8. Include use-case ***Repair Walls/Ceiling/Floor*** for the ED, OR Suite, and Sterile Storage Room.

Use-Case 13 – *Make Repairs to Unit*

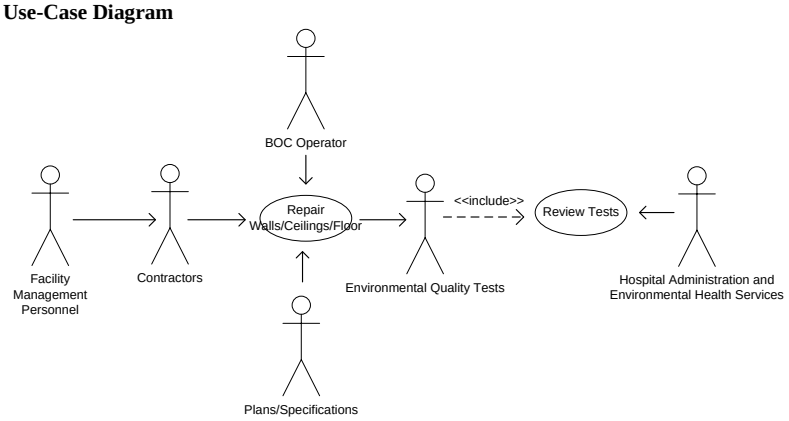
1. **Brief Description**
   This use-case describes the process taken by the Mechanical Shop Mechanic to make the needed repairs to the HVAC Unit.
2. **Use-Case Diagram**



3. **Preconditions**
   - The Mechanical Shop Mechanic has access to the needed Mechanical Specifications.
   - The Mechanical Shop Mechanic has the knowledge needed to diagnose the problem with the HVAC Unit.
   - The needed replacement Equipment is available to make the repair.
4. **Basic Flow**
   1. The Mechanical Shop Mechanic receives notification from Facility Management Personnel that there was a leak at the Air Handler, with a specific ID, with the chiller supply line.
   2. The Mechanical Shop Mechanic arrives on scene to begin diagnosis of the system.
   3. The Mechanical Shop Mechanic begins to diagnose the problem by checking the flow of water through the unit and notices that that on the chiller return line the pressure is low.
   4. The Mechanical Shop Mechanic decides that the symptoms point to a problem with the air handler coil.
   5. The Mechanical Shop Mechanic retrieves a replacement air handler coil from the supply room in the Mechanical Shop.
   6. The Mechanical Shop Mechanic disconnects the chiller supply line from the air handler coil.
   7. The Mechanical Shop Mechanic removes and replaces the coil from the air handler unit.
   8. The Mechanical Shop Mechanic reattaches the supply line to the air handler unit.
   9. The Mechanical Shop Mechanic turns the supply line back on to check for leaks.
   10. The Mechanical Shop Mechanic sees there are no leaks, so begins the steps to get the Air Handler back on line.

Use-Case 14 – *Repair Walls/Ceiling/Floor*

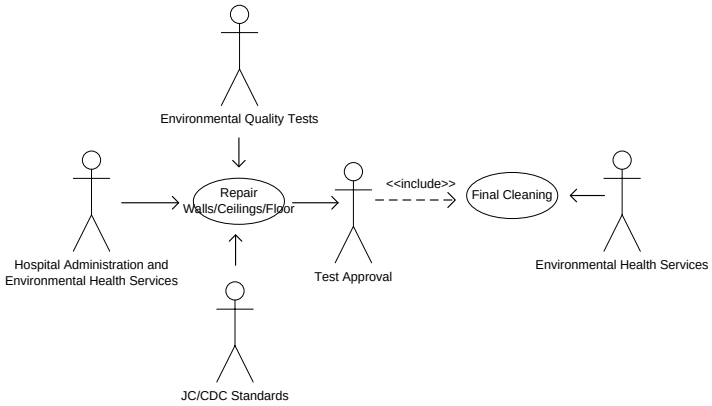
1. **Brief Description**
   This use-case describes the process taken by the Contractor to make the needed repairs to the walls/ceilings/floor.
2. **Use-Case Diagram**



3. **Preconditions**
   - The Contractors are capable and available to do the needed repairs.
4. **Basic Flow**
   1. Contractor receives call from Facility Operations Personnel.
   2. Contractor arrives at facility.
   3. Contractor reports to BOC Operator to sign in and get keys.
   4. Contractor goes to scene.
   5. Contractor sets up drying equipment and encloses areas to dry areas of wall and ceiling.
   6. Contractor replaces pieces of wall and ceiling that need to be replaced.
   7. Contractor cleans areas once repairs are made.
   8. Contractor conducts Environmental Quality Tests for both air quality and moisture level of dried walls and ceiling.
   9. Contractor sends results of tests to Hospital Administration and Environmental Health Services for ***Review of Tests***.
   10. Contractor reports to BOC Operator to sign out and return access keys.

Use-Case 15 – *Review of Tests*

1. **Brief Description**
   This use-case describes the process of the Hospital Administration and Environmental Health Services approving the test results.
2. **Use-Case Diagram**

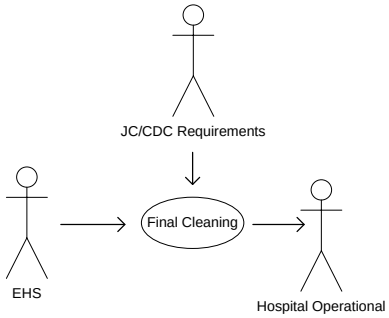


3. **Preconditions**
   - Both Environmental Health Services and Hospital Administration have knowledge of CDC and JC requirements and know the appropriate moisture and air quality levels.

4. **Basic Flow**
    1. Administration receives test results from contractor of air quality and moisture levels.
    2. Administration checks the results of the testing to healthcare standards.
    3. Noticing that the levels are within those specified by the CDC and JC and meet health regulations, the Administration authorizes ***Final Cleaning***.

Use-Case 16 – *Final Cleaning*

1. **Brief Description**
   This use-case describes the final cleaning process by EHS
2. **Use-Case Diagram**



3. **Preconditions**
    - EHS understand the requirements for the terminal cleaning.
    - EHS uses the proper tools, equipment, and cleaning chemicals/solutions when conducting the cleaning.
4. **Basic Flow**
    1. EHS dispatches workers to perform a terminal clean of work areas.
    2. EHS follows CDC and infection control guidelines.
    3. EHS notifies Administration of completed clean.

Case	Step	Involved Information	Format	User	Origin (Phase, Process, Description)	System Interface
1	4	Work Order	Standard Form	BOC/FM	O, CL, At time of call	Building Control system
1	5	Water Incursion Report	Standard Form	BOC/FM	O, CL, At time of call	Building Control system
1	6	Work Order Number		BOC/FM/Administration	O, FM, Output from Building Control System	Building Control System
1	7	Nurse		BOC	O, CL, From Call	Log Book
1	7	Problem Type		BOC	O, CL, From Call	Log Book
1	7	Work Order Number		BOC	O, FM, From Work Order	Log Book
1	8	Location	In Water Incursion Report	BOC/FM/Administration	O, CL, From Call	Building Control System
1	8	Use of Room	In Water Incursion Report	BOC/FM/Administration	O, CL, From Call	Building Control System
1	8	Date, Day, Time	In Water Incursion Report	BOC/FM/Administration	O, CL, From Call	Building Control System
1	8	Identified Hazards	In Water Incursion Report	BOC/FM/Administration	O, CL, From Call	Building Control System
1	8	Initial Action	In Water Incursion Report	BOC/FM/Administration	O, CL, From Call	Building Control System
1	10	Location	Page to Mechanic	Maintenance Mech	R, FM, From Work Order	Building Control System
1	10	Use of Room	Page to Mechanic	Maintenance Mech	R, FM, From Work Order	Building Control System
1	10	Expected Hazards	Page to Mechanic	Maintenance Mech	R, FM, From Work Order	Building Control System
1	11	Damages - Standing Water	add to Water Incursion Report	BOC/Maintenance Mechanic/FM/Admin	R, R, Observation	Building Control system
1	12	Level I Team Contact		BOC/Administration	O, CL, EOP	Emergency Operation Plan
1	15	Call Log		BOC/Nursing Administration	R, CL, New Call - Nursing Admin.	BOC Log Book
1	16	Extent of Damage	Water Incursion Event Form	BOC/FM/Administration	R, CL, From Call - Nursing Observ.	Building Control system
1	16	Source of Water	Water Incursion Event Form	BOC/FM/Administration	R, CL, From Call - Nursing Observ.	Building Control system
1	16	Cause of Problem	Water Incursion Event Form	BOC/FM/Administration	R, CL, From Call - Nursing Observ.	Building Control system
1	16	Has Source been Eliminated	Water Incursion Event Form	BOC/FM/Administration	R, CL, From Call - Nursing Observ.	Building Control system
1	16	Steps to Clean the Area	Water Incursion Event Form	BOC/FM/Administration	R, CL, From Call - Nursing Observ.	Building Control system
1	16	Is Access Restrcited	Water Incursion Event Form	BOC/FM/Administration	R, CL, From Call - Nursing Observ.	Building Control system
1	16	Are Patients/Visitors Evac.	Water Incursion Event Form	BOC/FM/Administration	R, CL, From Call - Nursing Observ.	Building Control system
1	16	Patients/Visitors Location	Water Incursion Event Form	BOC/FM/Administration	R, CL, From Call - Nursing Observ.	Building Control system
1	16	Risk/Damage Level	Water Incursion Event Form	BOC/FM/Administration	R, CL, From Call - Nursing Observ.	Building Control system
1	17	Level II Team Contact		BOC/Administration	O, CL, EOP	Emergency Operation Plan
1	20	Contractor Login	Date/Time/Work Order #	BOC/FM	R, R, Contractor Arrival	BOC Contractor Log
1	21	Key Sign-out	Contractor/Date/Time/Key #	BOC/FM	R, R, Contractor Arrival	BOC Key Log
1	22	Contractor Log-out	Date/Time/Work Order #	BOC/FM	R, R, Contractor Complete	BOC Contractor Log

Case	Step	Involved Information	Format	User	Origin (Phase, Process, Description)	System Interface
1	3A.1	System Alarm	Graphic - Location/Type/Date/Time	BOC/FM	O, FM, Alarm Sensor Triggered	Building Automation System
1	3A.3	Contractor Work Order Information	Contractor/Location/Time	BOC/FM	O, FM, Current contracted work	BOC Contractor Log
1	3A.5	Maintenance Mechanic Page	Location/Alarm Type	BOC/FM/Maintenance Mech	O, FM, Alarm Data	Building Automation System
1	3A.6	Work Order	Standard Form	BOC/Mechanical Shop	R, FM, Use info from Maintenance Mech	Building Control system
2	2	Work Order	Standard Form	BOC/FM	At Time of Call	Building Control system
2	2	Room	Standard Form	BOC/FM	At Time of Call	Building Control system
2	2	Location	Standard Form	BOC/FM	At Time of Call	Building Control system
2	2	Noticed Damages	Standard Form	BOC/FM	At Time of Call	Building Control system
2	3	Work Order Number		BOC		BOC Log Book
2	3	Reporting Person		BOC		BOC Log Book
2	3	Location		BOC		BOC Log Book
2	3	Date/Time		BOC		BOC Log Book
2	3	Mechanic Page		BOC/Maintenance Mech		Paging System
2	3	Location		Maintenance Mech	From Work Order	
2	3	Problem		Maintenance Mech	From Work Order	
2	7	Problem (update)		BOC/Maintenance Mech	Repair	Building Control System (Work Order)
2	1A.1	Moisture System Alarm	Electronic Message	BOC	Operations	Building Automation System
2	1A.1	Work Order Status		BOC	Repair	BOC Contractor Log
2	1A.2	Mechanic Page		BOC/Maintenance Mech		Paging System
2	1A.6	Work Order Creation		BOC		Building Control System (Work Order)
2	1A.6	Location	in Work Order	BOC	Operations - Alarm System	Building Control System (Work Order)
2	1A.7	Identified Problem		BOC	Repair - Mechanic Observation	Building Control System (Work Order)
2	1A.8	Date/Time		BOC	Repair - Mechanic Observation	Building Control System (Work Order)
3	3	Alarm Type	Call from BOC/Electronic Message	Maintenance Mech	Operations - Alarm System	Building Automation System

Case	Step	Involved Information	Format	User	Origin (Phase, Process, Description)	System Interface
3	3	Alarm Location	Call from BOC/Electronic Message	Maintenance Mech	Operations - Alarm System	Building Automation System
3	3	Unit ID	Call from BOC/Electronic Message	Maintenance Mech	Operations - Alarm System	Building Automation System
3	5	Unit # and sensor	Barcode	Maintenance Mech	C, M, Coded at installation	Mechanical Drawings
3	6	Identified Problem		Maintenance Mech	Repair - Mechanic Observation	
3	7	Identified Problem	in Work Order	BOC	Repair - Mechanic Observation	Building Control System (Work Order)
3	8	Repair		Maintenance Mech	C, M/SP/S, Mechanical dwgs and specs	Mechanical Drawings and Specifications
3	9	Repair Completed	in Work Order	BOC	Repair	Building Control System (Work Order)
4	1	Situation Report	Call from BOC	Maintenance Mech	CL - Nurse report	
4	1	Location	Call from BOC	Maintenance Mech	CL - Nurse report	
4	2	Location		Maintenance Mech	D	CD (building layout)
4	4	Access Information		Maintenance Mech	D	CD (building layout)
4	5	Troubleshoot Problem		Maintenance Mech	C, M/SP/S, Mechanical dwgs and specs	Mechanical Drawings and Specifications
4	6	Identified Problem		Maintenance Mech	Repair - Mechanic Observation	
4	7	Mitigate		Maintenance Mech	C, M/SP/S, Mechanical dwgs and specs	Mechanical Drawings and Specifications
4	8	Repair		Maintenance Mech	C, M/SP/S, Mechanical dwgs and specs	Mechanical Drawings and Specifications
4	9	Identified Problem		BOC	Repair - Mechanic Observation	Building Control System (Work Order)
4	9	Location		BOC	C, M/SP/S, Mechanical dwgs and specs	Building Control System (Work Order)
4	9	Unit ID		BOC	C, M/SP/S, Mechanical dwgs and specs	Building Control System (Work Order)
4	6A.2	Unit ID	Call to BOC	BOC	C, M/SP/S, Mechanical dwgs and specs	Building Control System (Work Order)
4	6A.2	Identified Problem	Call to BOC	BOC	Repair - Mechanic Observation	Building Control System (Work Order)
4	6A.2	Location	Call to BOC	BOC	C, M/SP/S, Mechanical dwgs and specs	Building Control System (Work Order)
4	6A.3	Dispatch Information	Page	BOC/Mechanical Shop		

Case	Step	Involved Information	Format	User	Origin (Phase, Process, Description)	System Interface
5	1	Work Order	Standard Form	Mechanical Shop	Repair - BOC Created	Building Control System (Work Order)
5	1	Location	in Work Order	Mechanical Shop	C, M/SP/S, Mechanical dwgs and specs	Mechanical Drawing and Specifications
5	1	Identified Problem	in Work Order	Mechanical Shop	Repair - BOC Created	Building Control System (Work Order)
5	1	Unit ID	in Work Order	Mechanical Shop	C, M/SP/S, Mechanical dwgs and specs	Mechanical Drawing and Specifications
5	2	Surgery Schedule		Mechanical Shop/Surgery Staff	CL, Schedule	Clinical Schedule
5	3	Line Location		Mechanical Shop	C, M/SP/S, Mechanical dwgs and specs	Mechanical Drawing and Specifications
5	3	Zoning		Mechanical Shop	C, M/SP/S, Mechanical dwgs and specs	Mechanical Drawing and Specifications
5	4	Removal Instructions		Mechanical Shop	C, M/SP/S, Mechanical dwgs and specs	Supplier/Manufacturer Information
5	5	Replacement parts	Part Number	Mechanical Shop/Supplier	C, S, Supplier information and part no.	Supplier/Manufacturer Information
5	5	Replacement instructions		Mechanical Shop	C, M/SP/S, Mechanical dwgs and specs	Supplier/Manufacturer Information
5	7	Line Location		Mechanical Shop	C, M/SP/S, Mechanical dwgs and specs	Mechanical Drawing and Specifications
5	8	Work Order	Standard Form	Mechanical Shop/BOC	update	Building Control System (Work Order)
5	2A.1	Clinical Schedule		Mechanical Shop/Surgery Staff	CL, Schedule	Clinical Schedule
5	2A.1	Zoning		Mechanical Shop	C, M/SP/S, Mechanical dwgs and specs	Mechanical Drawing and Specifications
5	2A.1	Line Location		Mechanical Shop	C, M/SP/S, Mechanical dwgs and specs	Mechanical Drawing and Specifications
5	2A.2	Clinical Schedule		Surgery Staff	CL, Schedule	Clinical Schedule
5	2A.3	Line Location		Mechanical Shop	C, M/SP/S, Mechanical dwgs and specs	Mechanical Drawing and Specifications
6	2	Alarm Type	Call from BOC	Maintenance Mechanic	Operation - Electronic Alarm	Building Automation System
6	2	Alarm Status	Call from BOC	Maintenance Mechanic	Operation - Electronic Alarm	Building Automation System
6	2	Unit ID	Call from BOC	Maintenance Mechanic	Operation - Electronic Alarm	Building Automation System
6	2	Alarm Location	Call from BOC	Maintenance Mechanic	Operation - Electronic Alarm	Building Automation System

Case	Step	Involved Information	Format	User	Origin (Phase, Process, Description)	System Interface
6	3	Unit ID	Barcode	Maintenance Mechanic	C, M, Coded at installation	Mechanical Drawings and Specifications
6	3	Location		Maintenance Mechanic	C, M/SP/S, Mechanical dwgs and specs	Mechanical Drawings and Specifications
6	4	Identify Problem		Maintenance Mechanic	Repair - Mechanic Observation	
6	5	Identified Problem		BOC	Repair - Mechanic Observation	Building Control System (Work Order)
6	4A.1	No Problem Found		Maintenance Mechanic	Repair - Mechanic Observation	
6	4A.2	Alarm Reset		Maintenance Mechanic/BOC	Operation - Electronic Alarm	Building Automation System
6	4A.3	Date/Time		BOC	Operation - Electronic Alarm	Alarm Log
6	4A.3	Mechanic Observation		BOC	Operation - Electronic Alarm	Alarm Log
7	3	Dispatch Order	Call from BOC	BOC/Level 1 Response Team	Repair - Mechanic Observation	
7	3	Location		BOC/Level 1 Response Team	Repair - Mechanic Observation	
7	4	Supply Location		Maintenance Mechanic	Operations - Stock Supplies	
7	4	Mitigate Problem Procedures		Maintenance Mechanic	Repair - Mitigate Problem	Emergency Operation Plan
7	7	Mechanical System Location		Maintenance Mechanic	Repair - Investigate	Mechanical Drawings and Specifications
7	8	Identified Problem		Maintenance Mechanic	Repair - Mechanic Observation	
7	8	Unit ID		Maintenance Mechanic	C, M, Coded at installation	Mechanical Drawings and Specifications
7	8	Location		Maintenance Mechanic	C, M/SP/S, Mechanical dwgs and specs	Mechanical Drawings and Specifications
7	11	Shut Down Procedures	Radio to Mechanical Shop	Maintenance Mechanic/Mechanical Shop	C, M/SP/S, Mechanical dwgs and specs	Mechanical Shop/Drawings
7	11	Back-up System Plans	Radio to Mechanical Shop	Maintenance Mechanic/Mechanical Shop	C, M/SP/S, Mechanical dwgs and specs	Mechanical Shop/Drawings
7	12	Shut Off Valve ID		Maintenance Mechanic	C, M/SP/S, Mechanical dwgs and specs	Mechanical Shop/Drawings
7	13	Air Handler Shut Down Procedures		Maintenance Mechanic	C, M/SP/S, Mechanical dwgs and specs	Mechanical Shop/Drawings
7	15	Identified Problem		BOC/Maintenance Mechanic	Repair - Mechanic Observation	
7	15	Affected Zones		BOC/Maintenance Mechanic	C, M/SP/S, Mechanical dwgs and specs	Mechanical Drawings and Specifications
7	9A.1	Shut Down Procedures	Electronic Database	Maintenance Mechanic	C, M/SP/S, Mechanical dwgs and specs	Facility Information Database
7	9A.1	Shut Off Valve ID	Electronic Database	Maintenance Mechanic	C, M/SP/S, Mechanical dwgs and specs	Facility Information Database

Case	Step	Involved Information	Format	User	Origin (Phase, Process, Description)	System Interface
7	9A.1	Shut Off Valve Location	Electronic Database	Maintenance Mechanic	C, M/SP/S, Mechanical dwgs and specs	Facility Information Database
7	3A.3	Identified Problem		Maintenance Mechanic	Repair - Mechanic Observation	
7	3A.3	Unit ID		Maintenance Mechanic	C, M/SP/S, Mechanical dwgs and specs	Mechanical Drawings and Specifications
7	3A.6	Identified Problem	Call to BOC	BOC	Repair - Mechanic Observation	Building Control System (Work Order)
7	3A.7	Supplier		Maintenance Mechanic	C, CD/SP, Finish Drawings (Tile type)	Construction Drawings/Finish Schedule
7	3A.7	Material ID		Maintenance Mechanic	C, CD/SP, Finish Drawings (Tile type)	Construction Drawings/Finish Schedule
8	1	Shut off Procedures		Maintenance Mech	C, CD - Plans	
8	1	Valve Location		Maintenance Mech	C, CD - Plans	
8	2	Unit ID		Mechanical Shop	Repair - Mechanic Observation	
8	2	Affected Zone		Mechanical Shop	C, M/SP/S, Mechanical dwgs and specs	Mechanical Drawings and Specification
8	3	Shut down procedures		Mechanical Shop	C, M/SP/S, Mechanical dwgs and specs	Mechanical Drawings and Specification
8	4	Valve Location		Maintenance Mech	C, M/SP/S, Mechanical dwgs and specs	Mechanical Shop/ Drawings
8	4	Valve ID Tag		Maintenance Mech	C, M/SP/S, Mechanical dwgs and specs	Mechanical Shop/ Drawings
8	5	Shut down process		Maintenance Mech	C, M/SP/S, Mechanical dwgs and specs	Mechanical Shop/ Drawings
8	2A.1	Unit ID		Mechanical Shop	C, M/SP/S, Mechanical dwgs and specs	Facilty Management Database
8	2A.2	Shut down process		Mechanical Shop	C, M/SP/S, Mechanical dwgs and specs	Manufacturer Specifications - Facility Management Database
9	1	Unit ID	Call to BOC	BOC	Repair - Mechanic Observation	
9	1	Location	Call to BOC	BOC		
9	2	Unit ID		BOC	C, M/SP/S, Mechanical dwgs and specs	Mechanical Zoning Plan
9	2	Clinical Space Effected		BOC/Clinical Admin	Repair - Effected areas	Mechanical Zoning Plan
9	3	Clinical Space Effected		BOC/Clinical Admin	Repair - Effected areas	Surgery Schedule
10	1	Water Incursion Report	Standard Form	BOC/Level I Response Team	Repair - BOC	Paging System
10	2	Location	Standard Form	Level I Response Team	Work Order	
10	2	Identified Problem	Standard Form	Level I Response Team	Work Order	

Case	Step	Involved Information	Format	User	Origin (Phase, Process, Description)	System Interface
10	2	Preliminary Response	Standard Form	Level I Response Team	Work Order	
10	2	Affected Zones	Standard Form	Level I Response Team	Work Order	
10	3	Extent of Damage		Level I Response Team	Response - Level I Observation	
10	3	Areas that are Damaged		Level I Response Team	Response - Level I Observation	
10	3	Hazards		Level I Response Team	Response - Level I Observation	
10	3	Response needed		Level I Response Team	Response - Level I Observation	
10	4	Location/Infection Risk Area Criteria		Level I Response Team	Response - Level I Observation	EOP - Location/Infection Risk Group Grid
10	4	Risk/Damage Incident Level		Level I Response Team	Response - Level I Observation	EOP - Location/Infection Risk Group Grid
10	5	Response Level		Level I Response Team	Response - Level I Observation	EOP - Extent of Damage Criteria for Response Team
10	9	Make Contact		BOC/Level I Response Team	Response - Level I Observation	EOP - Response Team
10	9	Location/Infection Risk Area Criteria		BOC	EOP	Building Control System (Work Order)
10	9	Risk/Damage Incident Level		BOC	EOP	Building Control System (Work Order)
10	9	Required Response		BOC	EOP	Building Control System (Work Order)
11	1	Water Incursion Report	Standard Form	BOC/Level II Response Team	Repair - BOC	Paging System
11	2	Location		Level II Response Team	Work Order	
11	6	Determine Damage		Level II Response Team	Response - Level II Observation	
11	8	Needed Repairs		Level II Response Team	Response - Level II Observation	Healthcare Standards
12	2	Needed Repairs		Facility Operations Personnel	Response - Level II Observation	
12	3	Repair Estimate		Facility Operations Personnel	Repair - Work to be done	CD, Plans and Specifications
12	4	Schedule of Repairs		Facility Operations Personnel	Repair - Work to be done	CD, Plans and Specifications
12	6	Needed Repairs		Mechanical Shop/Contractors	Response - Level II Observation	CD, Plans and Specifications
13	1	Identified Problem		Mechanical Shop Mechanic	Repair - Work Order	Building Control System (Work Order)

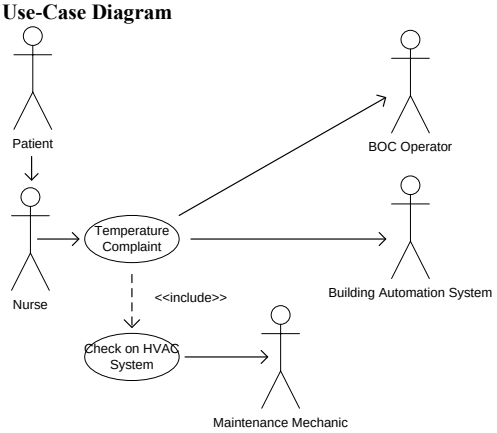
Case	Step	Involved Information	Format	User	Origin (Phase, Process, Description)	System Interface
13	1	Location		Mechanical Shop Mechanic	Repair - Work Order	Building Control System (Work Order)
13	1	Unit ID		Mechanical Shop Mechanic	Repair - Work Order	Building Control System (Work Order)
13	2	Problem Cause		Mechanical Shop Mechanic	Repair - Diagnose	Mechanical drawings and specifications
13	5	Cause Identified		Mechanical Shop Mechanic	Repair - Diagnose	Building Control System (Work Order)
13	5	Water Coil Replacement Procedures		Mechanical Shop Mechanic	C, M/SP/S, Mechanical dwgs and specs	Mechanical drawings and specifications
13	10	Air Handler Start Procedures		Mechanical Shop Mechanic	C, M/SP/S, Mechanical dwgs and specs	Mechanical drawings and specifications
14	3	Room Keys		BOC/Contractor		Key Log/Contractor Log
14	5	Needed Repairs		Contractor	Repair - Work Order	Building Control System (Work Order)
14	5	Needed Repairs		Contractor	Repair - Work Order	Healthcare Standards
14	8	Environment Quality - Air Test		Contractor	Repair - Completed Work	Healthcare Standards
14	8	Environment Quality - Moisture Levels		Contractor	Repair - Completed Work	Healthcare Standards
15	1	Environment Quality - Air Test		Adminstration	Repair - Contractor Tests	Healthcare Standards
15	1	Environment Quality - Moisture Levels		Adminstration	Repair - Contractor Tests	Healthcare Standards
16	1	Terminal Cleaning Requirements		Environmental Health Services	Repair - Completed Work	Healthcare Standards

Appendix K: Case Study 2 – Use-Cases and Analysis

This appendix is referenced from section 3.2 and contains the UML Use-Case descriptions and diagrams that are part of the Case Study 2 analysis. This appendix contains the complete use-cases and the information tracking table that was used to analysis the information needs of each independent task within the use-case sequence. The reasoning behind the use of the UML Use-Cases and how they were beneficial to the analysis and product model development is discussed in section 3.1.

Use-Case 1 – *Temperature Complaint*

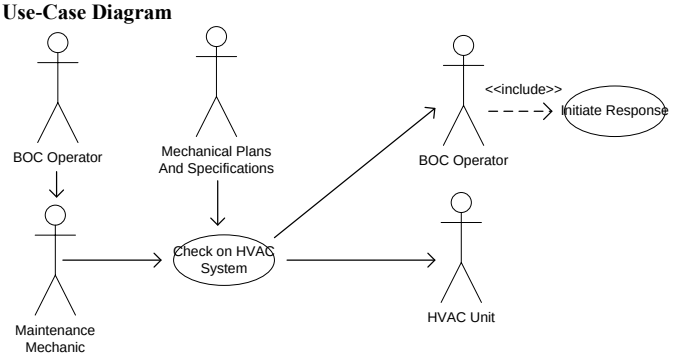
1. **Brief Description**
   This use-case describes the initial response to a temperature complaint.
2. **Use-Case Diagram**



3. **Preconditions**
   - The BOC Operator and Nurse have access to the phone system
   - The BOC Operator has direct access to the Building Automation System
   - The Building Automation is online and connected to temperature sensors and mechanical status alarms.
   - The Nurse does not have direct control of the temperature in the patient rooms.
4. **Basic Flow**
   1. The Nurse visits a patient room to check on a Patient alarm.
   2. The Nurse receives a temperature complaint from the Patient.
   3. The Nurse calls the BOC Operator with a complaint that the temperature within the patient rooms is too warm.
   4. The Nurse gives the BOC Operator the location of the rooms with problems.
   5. The BOC Operator checks within the Building Automation System of the temperature settings within the rooms.
   6. The BOC Operator sees that the actual temperature readings are outside of the range of what the thermostat is set.
   7. The BOC Operator determines that there is a problem with the system that it is blowing warmer air than the thermostat is set for.
   8. The BOC Operator pages the Maintenance Mechanic to look into the air handler unit in question, within the location of the unit and unit ID.
   9. Maintenance Mechanic completes ***Check on HVAC System.***
5. **Alternative Flows**
   4A. The BOC Operator receives an alarm from the Building Automation System that rooms are not within the desired temperature range.
   - .1 The BOC Operator checks on the alarm.
   - .2 The BOC Operator dispatches, through a page and coded information, the Maintenance Mechanic.
   - .3 The BOC Operator gives the Maintenance Mechanic the needed information of location and unit ID to locate and access the system.
   - .4 Return to step 9.

Use-Case 2 – *Check on HVAC System*

1. **Brief Description**
   This use-case describes the Maintenance Mechanics response in checking on the status of the HVAC System in the area of where the Temperature complaint was received.
2. **Use-Case Diagram**

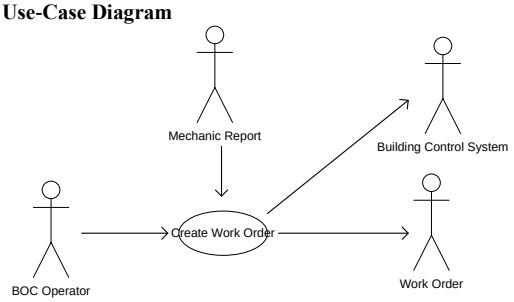


3. **Preconditions**
   - The Maintenance Mechanic and BOC Operator have access to the paging system.
   - The Maintenance Mechanic knows where the access to the HVAC Unit is located.
   - The Maintenance Mechanic has knowledge of the workings of the system, or has direct access to the Mechanical Plans and Specifications
4. **Basic Flow**
   1. Maintenance Mechanic receives a page from the BOC Operator to check on the HVAC Unit in question.
   2. Maintenance Mechanic locates the unit on the floor where the problem was reported.
   3. Maintenance Mechanic locates the access hatch near the unit.
   4. Maintenance Mechanic begins to diagnose unit.
   5. Maintenance Mechanic verifies that fan is working.
   6. Maintenance Mechanic checks coil and notices it does not appear to be cold.
   7. Maintenance Mechanic locates additional air handler units on zone.
   8. Maintenance Mechanic checks coil and notices they are not cold.
   9. Maintenance Mechanic backtracks system for diagnosis.
   10. Maintenance Mechanic goes to basement to check flow gauges of chiller line.
   11. Maintenance Mechanic notices water flowing from the main chiller line in the basement at a break near the wall.
   12. Maintenance Mechanic locates the shut-off valve near where the chiller line comes into the building.
   13. Maintenance Mechanic turns the shut-off valve to shut off the water.
   14. Maintenance Mechanic notifies BOC Operator who ***Initiates Response***.
5. **Alternative Flows**
   5a. Maintenance Mechanic identifies that the fan is not working properly on the unit.
   .1 Maintenance Mechanic notifies BOC Operator to create a work order to replace fan.

   7a. Maintenance Mechanic verifies that other units along the chiller line are cold.
   .1 Maintenance Mechanic decides that the probably is with the chiller coil within the air handler unit.
   .2 Maintenance Mechanic notifies BOC Operator to create a work order to replace the coil.
   .3 Maintenance Mechanic notifies local nurse that the air handler unit needs to be repaired.
   .4 The BOC Operator completes the use-case ***Create Work Order***.

Use-Case 3 – *Create Work Order*

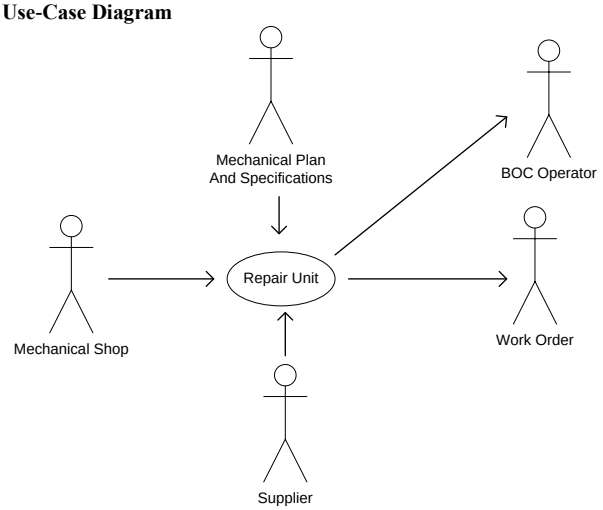
1. **Brief Description**
   This use-case describes the process taken by the BOC Operator to Create a Work Order.
2. **Use-Case Diagram**



3. **Preconditions**
   - The BOC Operator has direct access to the Building Control System.
   - The Building Control System is attached to the network.
4. **Basic Flow**
   1. BOC Operator collects the information from the Maintenance Mechanic about what needs to be done by the Mechanical Shop.
   2. BOC Operator creates a work order in the Building Control System.
      {Output Work Order Number and Report}
   3. BOC Operator notifies Mechanical Shop of work order to complete work.
   4. BOC Operator schedules work with local nursing unit of effected unit.
   5. The Mechanical Shop completes the use-case ***Repair Unit***.

Use-Case 4 –*Repairs Unit*

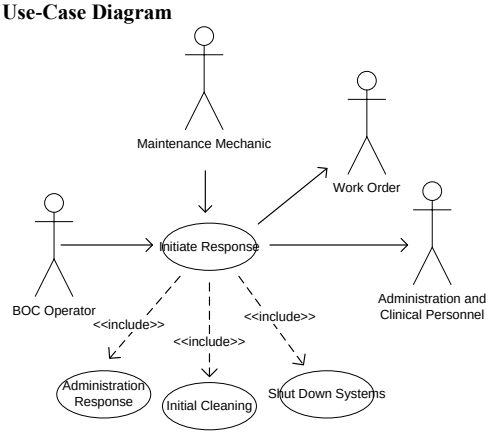
1. **Brief Description**
   This use-case describes the Mechanical Shop's process of repairing the HVAC Unit.
2. **Use-Case Diagram**



3. **Preconditions**
   - The Mechanical Shop has access to the replacement parts.
   - Mechanical Shop knows where to access the unit.
   - Mechanical Shop has access to needed specifications and plans.
4. **Basic Flow**
   1. Mechanical Shop receives a Work Order Report.
   2. Mechanical Shop checks for replacement parts needed based on initial diagnosis.
   3. Mechanical Shop gets the replacement parts from supplier (or stock room) to complete the work.
   4. Mechanical Shop goes to unit needing repair based on unit ID and location supplied by the work order.
   5. Mechanical Shop access unit through the access hatch.
   6. Mechanical Shop checks on system diagnosis.
   7. Mechanical Shop shuts down unit following manufacturer protocol.
   8. Mechanical Shop replaces the part that needs to be replaced.
   9. Mechanical Shop starts unit back up, following manufacturer protocol.
   10. Mechanical Shop checks that unit is working properly.
   11. Mechanical Shop notifies BOC that work is complete and Work Order is updated.

Use-Case 5 – *Initiate Response*

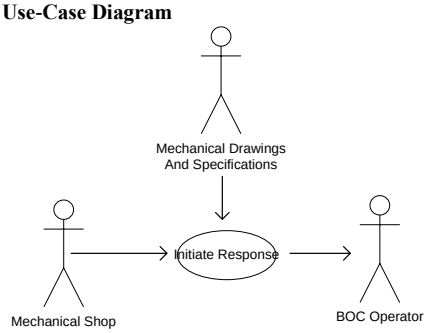
1. **Brief Description**
   This use-case describes the initial response from the BOC Operator in responding to the main chiller line break.
2. **Use-Case Diagram**



3. **Preconditions**
   - BOC Operator has access to Building Control System to create Work Order.
   - BOC Operator has contact information and knows the proper contacts for the response.
4. **Basic Flow**
   1. BOC Operator receives report from Maintenance Mechanic that there is a leak in the basement of the main chiller line that was then shut off.
   2. The BOC Operator creates a Work Order number in the Building Control System.
   3. The BOC Operator checks the mechanical zoning sheets to check what areas of the campus are affected.
   4. The BOC Operator notifies the proper administration, nursing, infection control, and security of the situation through a page and they are dispatched to the scene.
   5. Include ***Administration Response.***
   6. The BOC Operator pages the mechanical shop to shut down the air conditioning system of the affected building.
   7. The Mechanical Shop completes ***Shut Down Systems.***
   8. The BOC Operator dispatches through pages, additional facility management personnel to the basement to help in initial clean up and response.
   9. Include ***Initial Cleanup***.
   10. The BOC Operator dispatches Environmental Health Services (EHS) to the scene to assist in clean-up.
5. **Alternative Flows**
   1A. BOC Operator receives an Alarm from the Building Automation System of a pressure flow sensor problem on the main chiller line.
   .1 BOC Operator sends a Maintenance Mechanic to check on the problem.
   .2 Maintenance Mechanic reports back to the BOC Operator of water in the basement.
   .3 Return to step 2.

Use-Case 6 –*Shut down systems*

1. **Brief Description**
   This use-case describes the process taken by the Mechanical Shop to shut down the HVAC System
2. **Use-Case Diagram**



3. **Preconditions**
   - The Mechanical Shop has access to the Mechanical System Drawings and Manufacturer Specifications

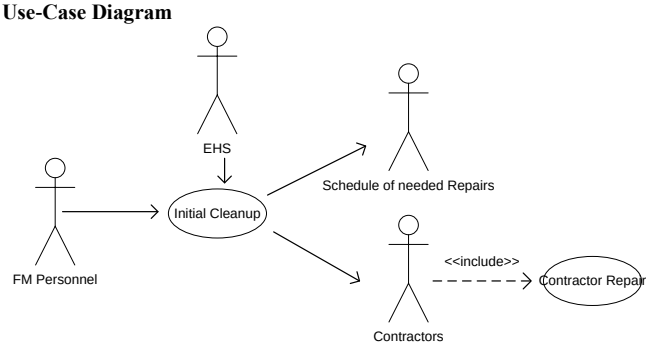
4. **Basic Flow**
    1. Mechanical Shop examines mechanical system drawings and manufacturer specifications and protocol for proper shut-down of system to prevent extended damage.
    2. Mechanical Shop shuts down systems.
    3. Mechanical Shop reports back to BOC Operator that the systems have been shut off.
5. **Alternative Flows**

    1A. Mechanical Shop is able to remotely shut down system through Building Automation System.

Use-Case 7 –*Initial Cleanup*

1. **Brief Description**

    This use-case describes the initial cleanup process.
2. **Use-Case Diagram**

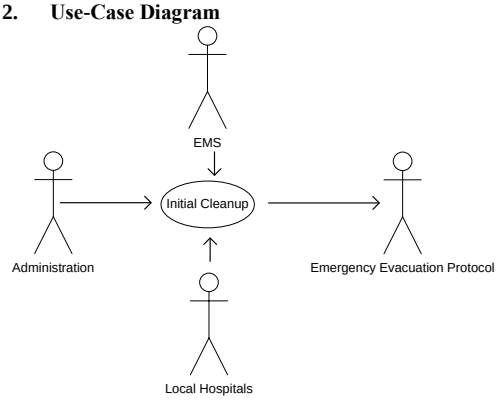


3. **Preconditions**
    - The FM Personnel are able to determine the amount of damage and needed repairs.
    - The FM Personnel are able to determine a possible schedule for repairs.
    - The Contractors are available to conduct the work.
4. **Basic Flow**
    1. The FM Personnel arrive on scene.
    2. The FM Personnel clean up the water with the assistance of EHS.
    3. The FM Personnel examine the extent of damage.
    4. The FM Personnel determine the needed repairs to get the pipe repaired and wall/ceiling/floor back to acceptable conditions.
    5. The FM Personnel develop a schedule for repairs.
    6. The FM Personnel get schedule approval from administration.
    7. The FM Personnel contact Contractors to conduct the work.
    8. Include ***Contractor Repair***.

Use-Case 8 –*Administration Response*

1. **Brief Description**

    This use-case describes the response process by hospital Administration and their determination to evacuate and move patients.
2. **Use-Case Diagram**

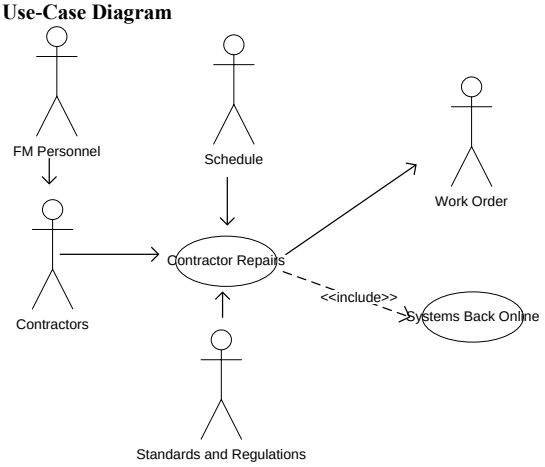


3. **Preconditions**
    - Administration is able to contact enough personnel from local EMS agencies to safely and effectively move the patients.
    - Area healthcare facilities have enough room for the patients that need to be evacuated.

4. **Basic Flow**
    1. Administration is notified of the problem by the BOC Operator.
    2. Administration determines that the building will become to hot to safely allow patients to stay in the affected building.
    3. Administration determines to evacuate the facility.
    4. Administration notifies other local healthcare facilities to the situation and determines where patients can be properly cared for.
    5. Administration notifies the local emergency management system to coordinate moving patients.
    6. Administration sets up the emergency evacuation protocol to make sure that each patient is moved with the appropriate records and receiving facilities have the needed information.

Use-Case 9 –*Contractor Repair*

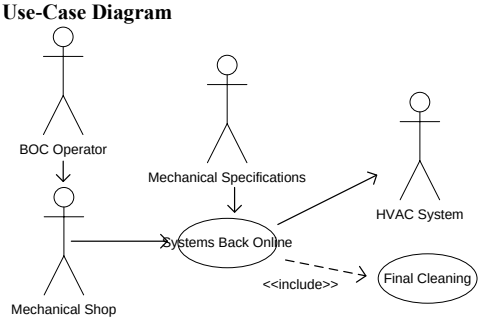
1. **Brief Description**
   This use-case describes the Contractor repair process
2. **Use-Case Diagram**



3. **Preconditions**
    - Contractors are capable and available to make the needed repairs.
    - Contractor is able to make repairs in scheduled timeline.
4. **Basic Flow**
    1. Contractor receives a call from FM Personnel about repairs that need to be complete.
    2. Contractor arrives at facility and checks in with BOC Operator to get keys and access to building.
    3. Contractor goes to location of pipe.
    4. Contractor fixes pipe and restores water to the HVAC System.
    5. Contractor notifies BOC of repairs made to pipe.
    6. Contractor fixes walls, ceiling, and floor around water break.
    7. Contractor notifies BOC of repairs made.
    8. BOC Operator updates Work Order.
    9. BOC Notifies Mechanical Shop to complete ***Systems Back Online***.

Use-Case 10 –*Systems back online*

1. **Brief Description**
   This use-case describes the Mechanical Shop's process of bringing the HVAC Systems back online.
2. **Use-Case Diagram**

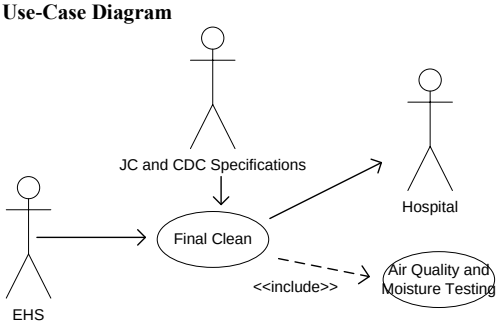


3. **Preconditions**
    - The Mechanical Shop has access to the proper procedures for getting the systems online.

4. **Basic Flow**
    1. The Mechanical Shop receives notification from BOC that contractor has finished repairs to the main chiller line.
    2. The Mechanical Shop starts to restore the HVAC system.
    3. The Mechanical Shop decides to do a slow cool of the building since it is so hot, as to not damage any of the systems by overworking them.
    4. Over the three day process, the building is finally brought up to temperature.
    5. The Mechanical Shop calls the BOC operator who notifies the Administration that the system is back online.
    6. Complete ***Final Cleaning.***

Use-Case 11 –*Final Clean*

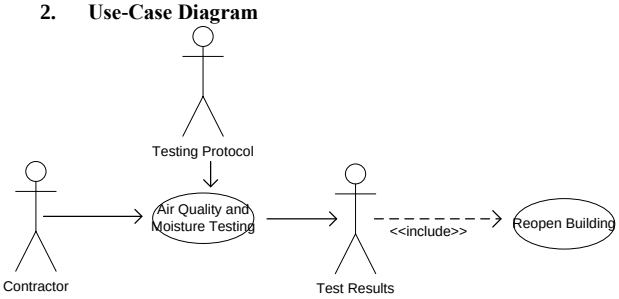
1. **Brief Description**
   This use-case describes the clean-up process.
2. **Use-Case Diagram**



3. **Preconditions**
    - EHS has an understanding of the regulations for cleaning the patient spaces are required by the CDC and the JC
4. **Basic Flow**
    1. EHS is notified once the building is back up to temperature, by the BOC to perform the final clean.
    2. EHS does a terminal clean and sanitation of each of the patient rooms and spaces.
    3. EHS notifies administration of cleaning complete.
    4. Administration notifies Contractor to conduct ***Air Quality and Moisture Testing***.

Use-Case 12 –*Air Quality and Moisture Testing*

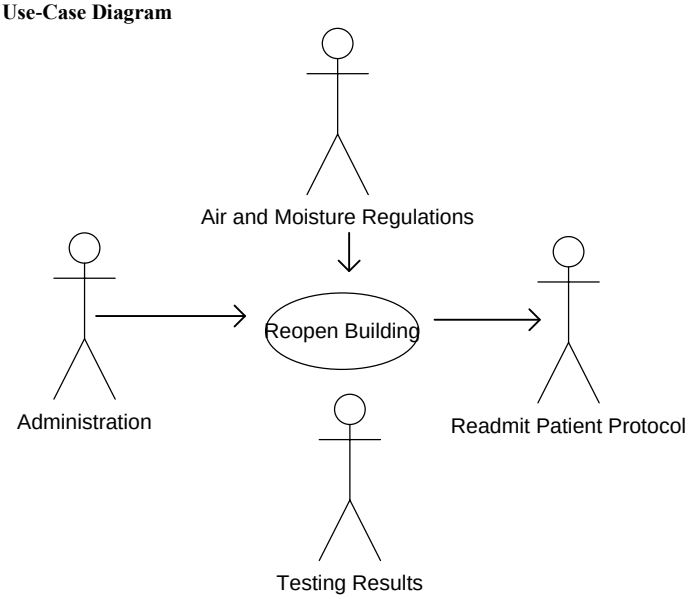
1. **Brief Description**
   This use-case describes the Air Quality and Moisture Testing procedures.
2. **Use-Case Diagram**



3. **Preconditions**
    - The Contractor has knowledge of the protocol for conducting the Air Quality and Moisture Tests.
    - The Contractor is capable of performing the tests and has access to the proper equipment.
4. **Basic Flow**
    1. The Contractor performs the Air Quality Test.
    2. The Contractor performs moisture tests.
    3. The Contractor turns the results into Administration.
    4. The Administration complete ***Reopen Building.***

Use-Case 13 –*Reopen Building*

1. **Brief Description**
   This use-case describes the process by the Hospital Administration to reopen the building.
2. **Use-Case Diagram**



3. **Preconditions**
   - The Administration has knowledge of the required air and moisture testing levels for an operating facility.
4. **Basic Flow**
   1. Administration receives air quality and moisture test results from the contractor.
   2. Administration checks that they are within limits required by the JC and CDC.
   3. Administration approves readmission of patients to facility.
   4. Administration contracts local facilities to transfer long-term patients back into facility.

Case	Step	Involved Information	Format	User	Origin (Phase, Process, Description)	System Interface
1	2	Temperature		Nurse	Operation - patient complaint	
1	3	Complaint		BOC	Operation - patient complaint	
1	3	Location		BOC	Operation - Nurse Report	
1	3	Temperature		BOC	Operation - Nurse Report	
1	3	Room occupancy		BOC	Operation - Nurse Report	
1	5	Temperature Settings	Bld Auto. Sys.	BOC	Commissioning - FM	Building Automation System
1	5	Complaint Location		BOC	Commissioning - FM	Building Automation System
1	6	Actual Temperature	Bld Auto. Sys.	BOC	Commissioning - FM	Building Automation System
1	6	Allowable Temperature		BOC	Commissioning - FM	Healthcare Standards
1	8	Air Handler Unit ID		Maintenance Mechanic	C, M, Mechanical Drawings	Mechanical Drawings
1	8	Location		Maintenance Mechanic	C, M, Mechanical Drawings	Mechanical Drawings
1	8	Problem		Maintenance Mechanic	Operation - Nurse Report	
2	1	Identified Problem		Maintenance Mechanic	Operation - Nurse Report	
2	1	Location		Maintenance Mechanic	C, M, Mechanical Drawings	
2	4	Troubleshooting Procedures	Diagnostic Manual	Maintenance Mechanic	C, M, Manufacturer Specifications	Mech. Specs. And Manuf. Guide
2	9	Supply Line for Unit		Maintenance Mechanic	C, M, Mechanical Drawings	Mechanical Drawings
2	9	Supply Line Location		Maintenance Mechanic	C, M, Mechanical Drawings	Mechanical Drawings
2	11	Problem Cause		Maintenance Mechanic	Repair - Mechanic Observation	Mech. Specs. And Manuf. Guide
2	11	Location		Maintenance Mechanic	Repair - Mechanic Observation	Mech. Specs. And Manuf. Guide
2	12	Shut off valve location		Maintenance Mechanic	C, M, Mechanical Drawings	Mechanical Drawings
2	13	Problem Cause		BOC	Repair - Mechanic Observation	Building Control System
2	13	Unit ID		BOC	C, M, Mechanical Drawings	Building Control System
2	13	Location		BOC	C, M, Mechanical Drawings	Building Control System
2	5A.1	Problem Cause		BOC	Repair - Mechanic Observation	Building Control System
2	5A.1	Unit ID		BOC	C, M, Mechanical Drawings	Building Control System
2	5A.1	Location		BOC	C, M, Mechanical Drawings	Building Control System
2	7A.1	Problem Cause		Maintenance Mechanic	Repair - Mechanic Observation	Mech. Specs. And Manuf. Guide
2	7A.1	Unit ID		Maintenance Mechanic	C, M, Mechanical Drawings	Mechanical Drawings
2	7A.1	Location		Maintenance Mechanic	C, M, Mechanical Drawings	Mechanical Drawings
2	7A.2	Needed Work		BOC	Repair - Mechanic Observation	Building Control System
2	7A.2	Unit ID		BOC	C, M, Mechanical Drawings	Building Control System
2	7A.2	Location		BOC	C, M, Mechanical Drawings	Building Control System
3	1	Location		BOC	C, M, Mechanical Drawings	Building Control System
3	1	Identified Problem		BOC	Repair - Mechanic Observation	Building Control System
3	1	Parts involved		BOC	Repair - Mechanic Observation	Building Control System
3	1	Unit ID		BOC	C, M, Mechanical Drawings	Building Control System
3	2	Work Order Number		BOC	Repair - Work Order Creation	Building Control System
3	3	Needed Work		Mechanical Shop	Repair - Mechanic Observation	Building Control System

Case	Step	Involved Information	Format	User	Origin (Phase, Process, Description)	System Interface
3	4	Schedule work		Mechanical Shop	Repair - Work Order Creation	Building Control System
3	4	Schedule work		Clinical Staff	Repair - Work Order Creation	clinical schedule system
4	1	Reported Problem		Mechanical Shop	Repair - Work Order	Building Control System
4	1	Initial Diagnosis		Mechanical Shop	Repair - Work Order	Building Control System
4	1	Location		Mechanical Shop	Repair - Work Order	Building Control System
4	1	Unit ID		Mechanical Shop	Repair - Work Order	Building Control System
4	3	Replacement Parts		Mechanical Shop	C, M, Manufacturer Specifications	Manufacturer Specifications
4	4	Unit ID		Mechanical Shop	Repair - Work Order	Mechanical Drawings
4	4	Location		Mechanical Shop	Repair - Work Order	Mechanical Drawings
4	7	Shut down procedures		Mechanical Shop	C, M, Manufacturer Specifications	Manufacturer Specifications
4	8	repair procedures		Mechanical Shop	C, M, Manufacturer Specifications	Manufacturer Specifications
4	9	start-up procedures		Mechanical Shop	C, M, Manufacturer Specifications	Manufacturer Specifications
4	11	Completed Work		BOC	Repair - Work Order	Building Control System
5	1	Identified Problem		BOC	Repair - Mechanic Response	Building Control System
5	1	Problem Mitigation		BOC	Repair - Mechanic Response	Building Control System
5	2	Work Order Number		BOC	Repair - Work Order Creation	Building Control System
5	3	Affected Areas		BOC	C, M, Mechanical Zoning Plans	Mechanical Drawings
5	4	Page Personnel		BOC	Facility Operations	Emergency Operations Plan
5	7	System Shut down		Mechanical Shop	C, M, Manufacturer Specifications	Manufacturer Specifications
5	1A	Alarm	Automated System	BOC	Operation - Building Automation System	Building Automation System
5	1A1	Identified Problem	Automated System	Maintenance Mechanic	Operation - Building Automation System	Building Automation System
5	1A2	Verify Problem		Maintenance Mechanic	Response - Mechanic Observation	
6	1	Shut down procedures		Mechanical Shop	C, M, Mech Dwgs and Man Specifications	Mechanical Drawings and Specifications
6	3	System Status Report		BOC	Response - Mechanical Shop	Building Control System
6	1A	System Status Report	Automated System	Mechanical Shop	Operation - Building Automation System	Building Automation System
7	4	Identified Damages		FM Personnel	Response - FM Observation	
7	4	Needed Repairs		FM Personnel	Response - FM Observation	Healthcare Standards
7	5	Schedule Repairs		FM Personnel	Response - Needed Repairs	Healthcare Standards
8	3	Evacuation Protocol		Administration	Response - Administration	Emergency Operation Plan
8	4	Local Facility Bed Availability		Administration	Response - Administration	Emergency Management System

Case	Step	Involved Information	Format	User	Origin (Phase, Process, Description)	System Interface
8	5	Emergency Management System - Transport		Administration and EMS	Response - Administration	Emergency Management System
8	6	Emergency Evacuation/Transfer Protocol		Administration and EMS	Response - Administration	Emergency Operation Plan
9	1	Needed Repairs		FM Personnel	Response - FM Observation	Healthcare Standards
9	1	Needed Repairs		Contractor	C, M, Mechanical and construction drawings	Building Control System
9	2	Keys/Access Codes		Contractor		Contractor log
9	4	Complete Repairs		Contractor	C, M, Mechanical and construction drawings	Mechanical Drawings and Specifications
9	5	Completed Repairs		BOC	Repair - Contractors	Building Control System
10	1	Work Completed		Mechanical Shop	Repair - Work Order Notification	Building Control System
10	2	Restart HVAC System		Mechanical Shop	C, M, Mechanical Specifications	Mechanical Specifications
11	1	Work Completed		EHS	Repair - Work Order Notification	Building Control System
11	2	Cleaning Procedures		EHS	Operations - Terminal Cleaning Procedures	Healthcare Standards
12	1	Perform Moisture and Air Test		Contractor	Repair - Work Completed	Healthcare Standards
12	3	Submit Results		Contractor	Repair - Work Completed	Operation Protocol
13	1	Review Moisture and Air Test		Administration	Repair - Contractor Testing	Healthcare Standards

Appendix L: Conceptual Model UML Use-Cases

This appendix is referenced from Chapter 5 section 5.2 and contains the UML Use-Cases that were developed to aid in the creation of the conceptual model. They were used to help organize and detail how the user can interact with the rest of the framework through the GUIs. The classes and attributes included in the Use-Cases in *Italics* are referenced from the product model that is discussed in Chapter 4.

Conceptual Model Use-Cases for response to mechanical water incursion problem.

The use-cases for the conceptual model show what the individual functions of the prototype would be. They are small portions of what the overall prototype would be used for. They show the information that is used and captured from the user at various points of the response and how that information is used to sort data to aid in the response. These use-cases are connected to the sequence diagrams that have previously been developed and are used in the basis of programming the Graphical User Interfaces (GUIs). A GUI interaction diagram is also developed to clearly show the path of data between the interfaces and the product model. This also shows the sequence of interfaces that incorporated into the conceptual model and prototype for aiding in situation response.

Use-case 1: Determine Actions Needed

Brief Description: In this use-case the basic information of the problem type and location are documented to help determine the actions that are needed to mitigate hazards and begin the response process.

Preconditions:

- The report from the reporting personnel must include the location and symptoms of the problem that was identified *or* the maintenance personnel that is called to the scene needs to notice the symptoms and be able to identify the location.
- The defined product model includes links of exposed clinical services to locations within the building model.

Basic Flow:

1. Run setEvent
2. *ProblemType* and *Location*, as reported into the work order system by the reporting personnel, is documented. (*ProblemType* = Water Incursion; *Location* = Operating Suite/Sterile Supply/ED)
3. Based on *Location*, the *ExposedClinicalService* is determined with the product model by the *ClinicalService* that "occupy" the location within the *Facility*.
    a. *Facility>Space>Zone* = Operating Suite/ Sterile Supply/ ED
    b. *ClinicalService* list of Operating Suite/Sterile Supply/ED = Surgery Staff, Operating Doctors, Surgical Nurses, Emergency Medicine, Central Supply
    c. ExposedClinicalServices = list of ClinicalServices
4. *getResponseProtocol* is run with inputs of *ExposedClinicalServices, Location,* and *ProblemType* are used to determine the proper response protocol.
5. *actionsRequired* is returned to the user based on the situation.
6. *actionsRequired* include **Use-case 2: Mitigate Hazards**
7. *actionsRequired* include **Use-case 3: Locating Source of Problem/Shut down system**
8. *actionsRequired* include **Use-case 4: Clinical Contacts – Risk Level and Damage Level Assessment**
9. *actionsRequired* include **Use-case 5: Set Affected (Broken) Components – Damages**
10. *actionsRequired* include **Use-case 6: Identify Hazards and Health Threats**

Use-case 2: Mitigate Hazards

Brief Description: Initial response for mitigating known hazards based on problem type and location and any hazards noticed (e.g. standing water or dripping water from ceiling) are taken into account and determined out to immediately mitigate them or at least reduce their risk of causing major problems.

Preconditions:

- The reporting person who is calling in the *Event* makes not of the hazards or the maintenance mechanic when he arrives on the scene will have to document the *IdentifiedHazards* into the system.
- NOTE: Some of the mitigating situations are common sense and may not need the system response but would be listed as a check list item to make sure everything is included.

Basic Flow:

1. Run mitigateEventHazards
2. Get *IdentifiedHazards* as reported in the *Event*
3. By type of hazard, return *ActionRequired*
    a. *IdentifiedHazards* = water dripping from ceiling, water saturated in ceiling, water pooling on floor
    b. *ActionsRequired* = contain water dripping, place "wet floor markers", secure the area, place barrier to prevent water spread (e.g. towels on floor).

Use-case 3: Locating Source of Problem/Shut down system

Brief Description: This use-case walks through the steps of determining the source of the problem and how to shut down an effected system.

Preconditions:

- The *ProblemType* and *Location* are needed based on the initial *Event* documentation.

Basic Flow:

1. Run *getSources*.
2. Based on *Location*, *ProblemType*, and *Symptoms* a list of *possibleSources* is returned.
3. *Symptoms* and the *ProblemType* are used to determine a list of *PossibleFailures*.
4. A list of *PossibleSources* is developed by crossreferencing the *PossibleFailures* with a *System* within a *Space* by listing the *Components* that can cause the *Symptoms* and reported *ProblemType*.
5. The user visually verifies which of the *PossibleSources* is the actual broken component.
6. The user identifies the *BrokenComponent* on the GUI.
7. Run *getComponentShutdown* based on the *BrokenComponent.*
8. *ShutdownProcedures* is returned.
9. A list of steps to shut down the affected system is given to the user.

Use-case 4: Clinical Contacts – Risk Level and Damage Level Assessment

Brief Description: Part of the response to any problem is determining the Risk and Damage Levels. With each of these certain responses may be needed and certain clinical personnel need to be notified of the situation to participate in the evaluation of the situation.

Preconditions:

Basic Flow:

1. Run *getClinicalContact*
2. Create *ClinicalContact* list
3. Add contacts based on *ExposedClinicalService* (additional contacts needed based on Risk and Damage Level)
4. Run *getRiskLevel*
5. *ClinicalServices*, *Location*, and *ProblemType* determine *RiskLevel* in *Protocol - EOP*
6. Run *setDamageLevel*
7. *Symptoms* and *IdentifiedHazards* determine *DamageLevel* in *Protocol - EOP*
8. *RiskLevel* and *DamageLevel* require additional *ClinicalContact* per *Protocol – EOP*

Use-case 5: Set Affected (broken) Components (Damages)

Brief Description: Components are broken that cause the problem, but the situation also causes damages to other components. This use-case documents all the broken components that will need to be repaired including the original source problem as well as any of the damages that are caused to other components (such as water damage to ceiling, walls, floor, etc.).

Preconditions: The BrokenComponent is identified in Use-case 3 as the source of the problem.

Basic Flow:

1. Run *SetAffectedComponents*
2. Noticed damages documented by *Location* and *Component*
3. *Component* that are affected are added to the *AffectedComponents* list.
4. Add in *BrokenComponents* which was identified as the cause of the problem to the *AffectedComponents*
5. Include **Use-case 7: Determine Repairs**

Use-case 6: Identify Hazards and Health Threats

Brief Description: Hazards from the damages, symptoms, and situation of the event are identified and connected to potential health threats. The health threats need to be mitigated and brought to the mind of relevant clinical services to follow proper protocol.

Preconditions:

Basic Flow:

1. Run *IdentifyHazards*
2. Document *IdentifiedHazards* associated with the *AffectedComponents* (e.g. water saturated wall)
3. Document visual hazards identified as part of the response protocol and include with *IdentifiedHazards*
4. Add *IdentifiedHazards* from *Event* to *IdentifiedHazards* list
5. Run *IdentifyHealthThreats*
6. Identify the *HealthThreats* that are associated with the *IdentifiedHazards*
7. List *MitigationProtocol* for each Health Threat type in a checklist form.

Use-case 7: Determine Repairs

Brief Description: There is a list of broken components. They can be arranged by the type of work they require and the type of contractor that is able to do the work. The system has a list of available contractors that are qualified for certain types of work.

Preconditions:

Basic Flow:

1. From *AffectedComponents* determine which can be done in house and which will be done by a contractor.
2. For in house repairs – are parts in stock for components that are being replaced – run *getParts*
3. Lists *InstockParts* with location of where they are located
4. Lists *SupplierParts* with a *Supplier* that can supply the parts
5. Digitally place purchase order for *SupplierParts*
6. Outputs to user component *Installation* information for making the repairs
7. Components determined to be completed by contractor from *AffectedComponents* list
8. *Contractor* is determined by *RepairType* that is needed
9. *Contractor* is contacted to complete the repairs
10. *RequiredTesting* is determined based on *Symptoms* and *Repairs* made. (Requires air quality and moisture level tests for saturated walls.

Appendix M: Conceptual Model GUI Interactions

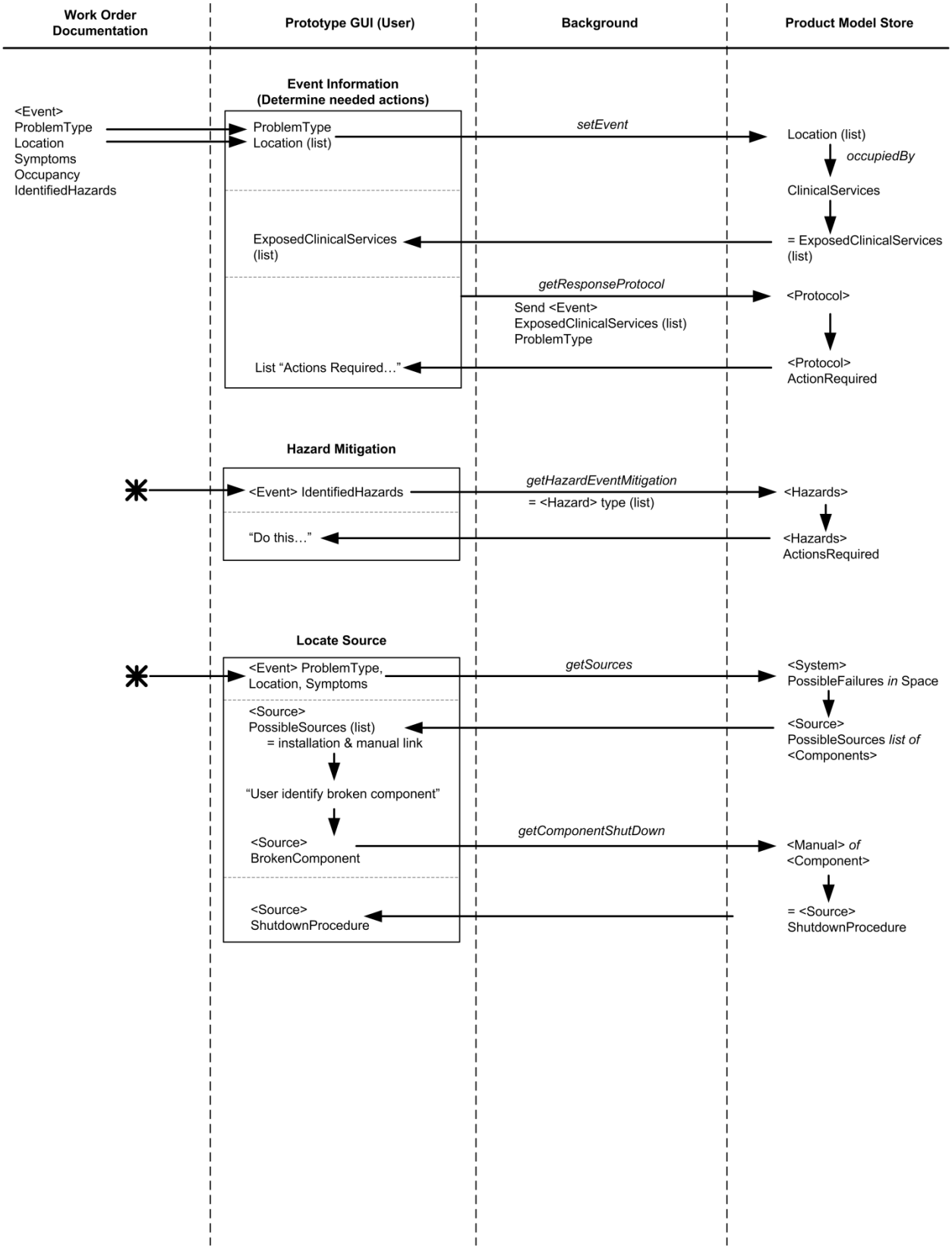
This appendix is referenced in Chapter 5 section 5.3. Several GUIs are used in the conceptual model and designed based on the use-cases that are shown in Appendix L. The map of those GUIs is included in this appendix. The information and operations that is included within the table match the information classes, attributes, and operations of the product model discussed in Chapter 4.

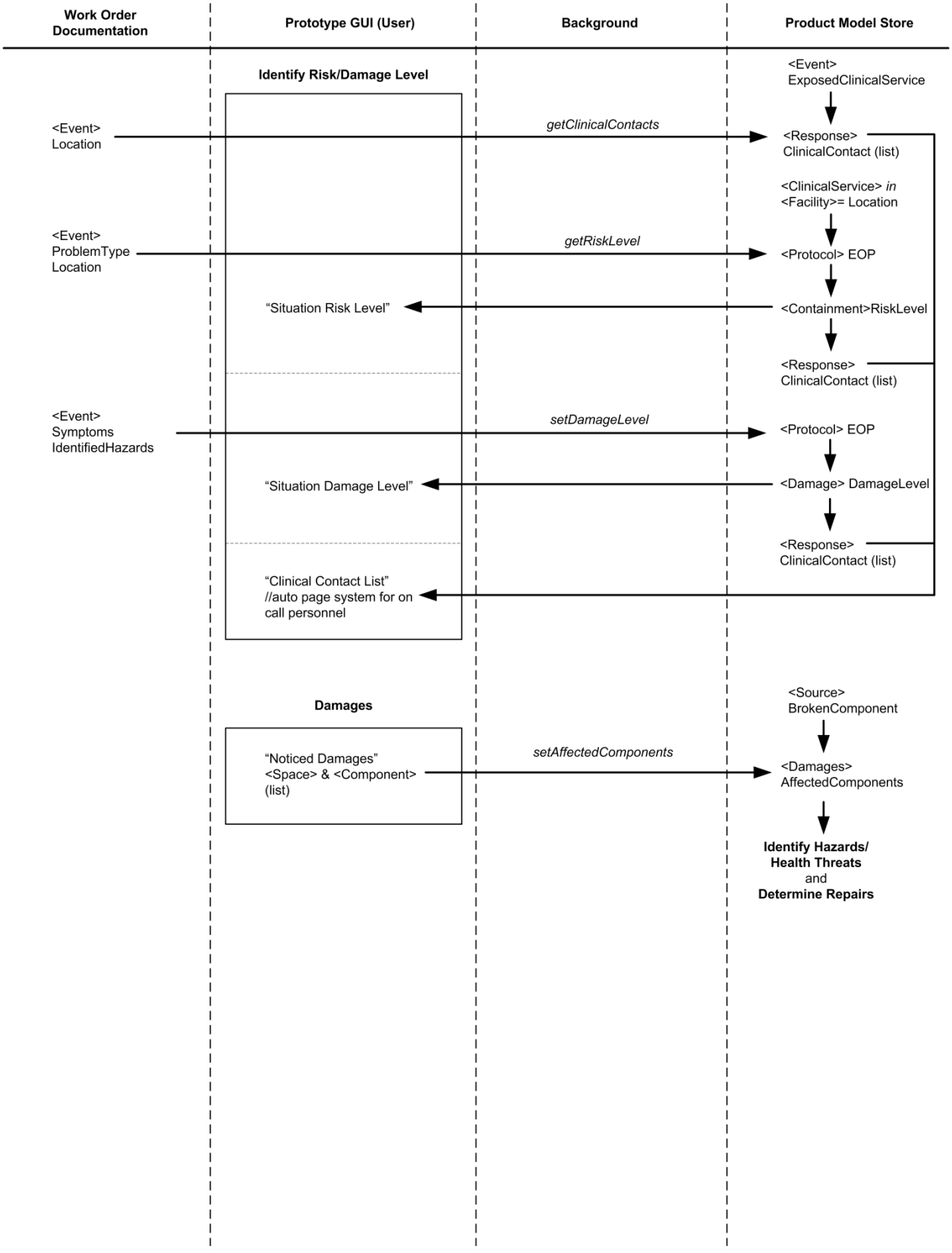
Words between <brackets> represent classes Example: <Event> is information from the Event class. Titles that are not in brackets and found under a class representation are attributes that can be found in the class.

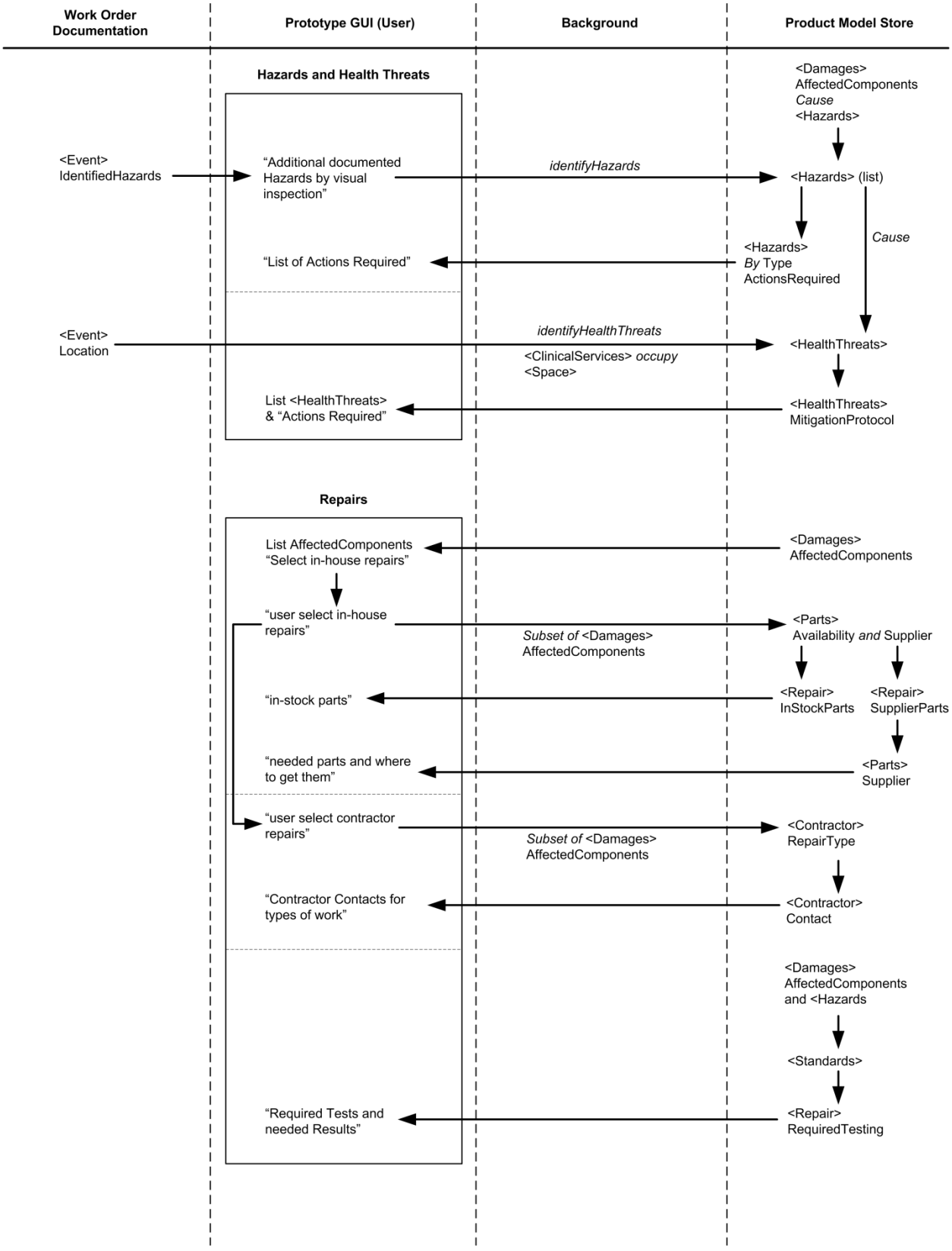
(list) means that within the system this attribute may contain a list of items. Example: Location (list) means that there can be more than one location that the event is taking place in. Location can hold a space name, such as "Operating Room 1", or a list of space names, such as "Operation Room 1, Operation Room 2, and Supply Closet 2".

Under the "Prototype GUI (User)" column, the boxes under titles represent a separate GUI page or tab. The GUIs are separated for different steps of the process. There are a total of 7 GUIs depicted on the map.

The arrows are messages between the columns. Within the "Background" column, statements in *Italic* are operations that are going on in the background.


Work Order Documentation
Prototype GUI (User)
Background
Product Model Store
Event Information (Determine needed actions)
<Event>
ProblemType
Location
Symptoms
Occupancy
IdentifiedHazards
ProblemType
Location (list)
setEvent
Location (list)
occupiedBy
ClinicalServices
= ExposedClinicalServices (list)
ExposedClinicalServices (list)
getResponseProtocol
<Protocol>
Send <Event>
ExposedClinicalServices (list)
ProblemType
<Protocol>
ActionRequired
List "Actions Required…"
Hazard Mitigation
<Event> IdentifiedHazards
getHazardEventMitigation
= <Hazard> type (list)
<Hazards>
"Do this…"
<Hazards>
ActionsRequired
Locate Source
<Event> ProblemType, Location, Symptoms
getSources
<System>
PossibleFailures in Space
<Source>
PossibleSources (list)
= installation & manual link
<Source>
PossibleSources list of
<Components>
"User identify broken component"
<Source>
BrokenComponent
getComponentShutDown
<Manual> of
<Component>
= <Source>
ShutdownProcedure
<Source>
ShutdownProcedure


Work Order Documentation
Prototype GUI (User)
Background
Product Model Store
Identify Risk/Damage Level
<Event>
Location
getClinicalContacts
<Event>
ExposedClinicalService
<Response>
ClinicalContact (list)
<ClinicalService> in
<Facility>= Location
<Event>
ProblemType
Location
getRiskLevel
<Protocol> EOP
"Situation Risk Level"
<Containment>RiskLevel
<Response>
ClinicalContact (list)
<Event>
Symptoms
IdentifiedHazards
setDamageLevel
<Protocol> EOP
"Situation Damage Level"
<Damage> DamageLevel
<Response>
ClinicalContact (list)
"Clinical Contact List"
//auto page system for on
call personnel
Damages
"Noticed Damages"
<Space> & <Component>
(list)
setAffectedComponents
<Source>
BrokenComponent
<Damages>
AffectedComponents
Identify Hazards/
Health Threats
and
Determine Repairs


Work Order Documentation
Prototype GUI (User)
Background
Product Model Store
Hazards and Health Threats
<Damages> AffectedComponents Cause <Hazards>
<Event> IdentifiedHazards
"Additional documented Hazards by visual inspection"
identifyHazards
<Hazards> (list)
Cause
<Hazards> By Type ActionsRequired
"List of Actions Required"
<Event> Location
identifyHealthThreats
<ClinicalServices> occupy <Space>
<HealthThreats>
List <HealthThreats> & "Actions Required"
<HealthThreats> MitigationProtocol
Repairs
List AffectedComponents "Select in-house repairs"
<Damages> AffectedComponents
"user select in-house repairs"
Subset of <Damages> AffectedComponents
<Parts> Availability and Supplier
"in-stock parts"
<Repair> InStockParts
<Repair> SupplierParts
"needed parts and where to get them"
<Parts> Supplier
"user select contractor repairs"
Subset of <Damages> AffectedComponents
<Contractor> RepairType
"Contractor Contacts for types of work"
<Contractor> Contact
<Damages> AffectedComponents and <Hazards
<Standards>
"Required Tests and needed Results"
<Repair> RequiredTesting