

FINAL PROGRESS REPORT

PROJECT TITLE: A PILOT STUDY FOR INTEGRATING FACILITY INFORMATION WITH HEALTHCARE INFORMATION TO IMPROVE PATIENT SAFETY

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1. STRUCTURED ABSTRACT

Purpose: The purpose of this study was to investigate the links and overlaps between facilities management information and healthcare delivery process information with a view toward identifying scenarios and use cases that can be used to develop systems and mechanisms to maximize the opportunities to improve patient safety.

Scope: The study was exploratory in nature and was limited to empirical investigations at the Hershey Medical Center – Penn State College of Medicine’s teaching hospital. No interventions or implementations were undertaken, as the primary focus was on identifying critical issues that could form part of a larger, more detailed study.

Methods: Various methods were employed in the conduct of the research. These included case studies, structured interviews with domain experts, content analysis of standards and guidance documents, process modeling (using BPMN), task analysis, use case development (using UML), failure mode effect analysis (FMEA), fault tree analysis (FTA), and cognitive walk-throughs.

Results: The study established that there is scope for improving patient safety through better coordination of the facilities management functions in a healthcare facility with the healthcare delivery processes. Numerous critical problem areas and gaps in standards were identified as worthy of more detailed studies. The outline features of a future ontology were also developed.

Key Words: Facilities management, Healthcare delivery process, Scenarios, FMEA, Process models

2. PURPOSE (Objectives of Study)

The specific aims of this study were to:

- (a) Investigate specific links and overlaps between patient/medical information and healthcare facility information (*Specific Aim 1*);
- (b) Develop scenarios and use cases for the critical use of healthcare facility information in relation to patient safety (*Specific Aim 2*);
- (c) Evaluate developed scenarios and use cases in a real-world setting for defining characteristics of a future ontology (*Specific Aim 3*).

3. SCOPE (Background, Context, Settings, Participants, Incidence, Prevalence)

Background: This pilot study was geared at generating initial scenarios and use cases that identify critical links between the healthcare facility information and the medical information from a patient safety perspective. In a hospital setting, a vast amount of dynamic data related to the availability of rooms, technical equipment, waste management, food services, heating ventilation and air conditioning

(HVAC) systems, and maintenance status is processed daily to provide for a smooth operation. Recent examples show that processing the healthcare facility information together with the medical information is important for tracking patients, caregivers, medical equipment, and medication as well as keeping track of contaminations and hospital-related infections. Putting healthcare data into its spatial context introduces a significant amount of additional information and enables the identification of patterns and reasoning mechanisms for usefully interpreting the available information. Although strategies for effective use of information technology to improve patient safety address the medical safety problems during the diagnosis and treatment, patient safety in relation to the healthcare environment and the role of healthcare facility information in this context has not yet been explored adequately. This approach involves developing an overall systems perspective that includes the link between medical information and whole-facility information, with content-aware healthcare facilities as the main goal.

Context and Setting: The research site was the Hershey Medical Center, which is the teaching hospital for the Penn State College of Medicine. A major outcome of the project was intended to be a characterization of facility management processes that have the most impact on the healthcare delivery process and how to maximize their positive impacts and minimize their negative impacts. The project also sought to identify scenarios where advanced or real-time access to facility information can enhance healthcare delivery and improve patient safety.

Participants: In addition to the research team, consisting of the Principal Investigator, senior personnel, and graduate students, other key participants included the facilities management department at Hershey Medical Center and a number of senior staff from several clinical departments – Nursing, Infection Control, Risk Management, Safety, Medical Information, Emergency, etc. The role played by these participants is outlined in the Methods section of this report.

4. METHODS (Study Design, Data Sources/Collection, Interventions, Measures, Limitations)

Specific Aim 1: This research activity was undertaken by a combination of methods, including analysis of existing guidelines and standards for healthcare facility management, process information tracking together with task analysis, and structured questionnaires and interviews with the facilities management personnel at Hershey Medical Center, which served as the case study healthcare facility.

Specific Aim 2: The scenarios and use cases for identifying the critical use of healthcare facility information in relation to patient safety were identified and modeled using a combination of BPMN (Business Process Modeling Notation) and Unified Modeling Language (UML).

Specific Aim 3: The achievement of this aim involved assessment of the case study scenarios using FMEA (Failure Mode Effects Analysis) and FTA (Fault Tree Analysis), cognitive walk-throughs of the healthcare facility with domain experts to establish the handling and impact of critical facility failure incidents, structured interviews with both facilities management staff and clinical personnel, and entity-relationship data modeling for developing an example ontology for use in characterizing the relationship between healthcare facilities (the “environment of care”) and the healthcare delivery process.

5. RESULTS (Principal Findings, Outcomes, Discussion, Conclusions, Significance, Implications)

The results of the study are presented below under appropriate headings that highlight the issues investigated and the key findings.

5.1 Investigation of Facility Management Effects on Patient Safety and Clinical Operations

This study was completed to identify links between facilities management and both patient safety events and clinical operations. In order to complete this study, case study analyses were utilized to document cases that demonstrate a link between facility management and patient safety. Possible case study topics were identified through literature review and meetings with hospital facilities management and clinical personnel. Cases were both planned and unplanned. Planned events are things such as regular maintenance of mechanical and electrical systems, whereas unplanned events typically happen without prior notice and involve some level of emergency response. Both planned and unplanned events have a link between facilities management personnel and patient safety or clinical operations. The patient safety events that were identified through the literature review and interviews are included in Table 1.

Table 1: Cases Linking Facility Management with Patient Safety

	Planned	Unplanned
Short Term (< 4 Hours)	Changing filters and cleaning coils	Climate problem in room Power outage Temperature in OR/Recovery out of range Pressure changes in pressure environments – Limited utility capacity Leave sink running and overflow
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 from insufficiently cleaned air units in walls Boiler goes offline Malfunctioning HVAC unit in OR Roof leak Pipe burst (and remediation) Knock off sprinkler head while cleaning (and remediation) Sewer backup causing central sterile offline Sewer contaminating sterile supplies
Long Term (>1 Week)	Unit Renovation – Containment and systems shut down Power strip replacement/electrical renovation	Mold or moisture damage previously unknown found during renovation Chiller pipe burst/Air conditioning shutdown

Of these cases of facility management effects on patient safety/clinical operations, four were selected for further investigation and analysis. The selected cases were:

Case 1: Malfunctioning HVAC unit in operating room (OR)

An HVAC Air Handler Unit above the operating suite's sterile supply had a defective chiller coil that began to leak. The water dripped through the ceiling tile and down the wall. The damage of the water had also damaged a wall within one operating room and the ceiling and wall of two emergency department bed bays on the lower floor. The situation occurred in the early morning hours on a Saturday. No patients were currently in any of the affected locations. The water in the sterile supply room was noticed by an operating room nurse, who promptly reported the situation to the control center operator. The operator initiated the response with the mechanic on duty and hospital administration. The unit was repaired, and contractors were brought in to repair the damages. The emergency room bays and operating room were repaired within 48 hours. The sterile supply was repaired in 5 days. The situation did not immediately affect or cause cancellations of any scheduled operating room procedures, as other rooms were still usable. The total damages, repairs, and contaminated supplies that needed to be replaced were estimated at a total of \$7 million.

Case 2: Chiller pipe burst/air conditioning shutdown

During a mid-summer heat wave, the main chiller line supplying a patient and clinic building on a hospital campus ruptured, causing the evacuation of the patients to other facilities. The problem was realized when the patients complained the rooms were too hot. The nurse contacted the building control center, who in turn had the on-call mechanic check on the problem. While diagnosing the problem, the mechanic noticed the main water main break. The administration of the hospital made the decision to evacuate, because the interior heat was starting to rise. The pipe was fixed within 24 hours. Due to the heat, it took several days to re-cool the facility so as to not overwork the air conditioning units. Once the facility was cooled, a terminal cleaning of the entire facility was needed before air quality testing. The patients were moved back in after about 10 days of the facility being closed.

Case 3: Sewer backup

A sewer main blockage developed as a result of flushing disposable wipes and other non-flushable materials into the sanitary system. The materials caused a complete blockage of the sewer line. The first indication of the problem was reported on the ground floor when water started to back up around floor drains. Removing the blockage took from morning to evening. The malfunctioning sewer line was cleared and made functional on the same day. While it was out of service, the sewage was pumped via a transfer pump to another sewer line. Dishwashers in the Food Service Department were not able to work that day, and disposable dishes were used instead. Finally, in the evening, all systems were back in service. A final cleaning of all work areas was conducted, and the problem was completely solved.

Case 4: Compliance with Power Strips/Surge Protector Regulation

To comply with institutional safety policy and Joint Commission requirements for power strips, facilities management initiated an electrical upgrade program to replace non-compliant power strips with compliant ones and add extra permanent electrical outlets. The facilities group provided education and notice to the campus community regarding the General Safety Electrical Equipment policy, which was provided by the Safety Group. Then, they canvassed the need to apply the correct power strip to the whole building and developed the inventory and purchased the compliant hospital-grade power strip. Providing healthcare-graded power strips increases patient and staff safety, decreases the complexity of making the right decision, and increases the likelihood of passing the Joint Commission inspection or regulatory. To address this, about 1700 power strips were replaced. These standard receptacles have green dots, and each cost about \$60. About \$180,000.00 was spent in 2010 to remove all the typical power strips and replace them with a hospital-grade surge protector.

These cases were documented as narratives with the aid of facilities management and clinical personnel from Hershey Medical Center. Once the narratives were created for each of the case studies, they were turned into process models using Business Process Model Notation (BPMN). Examples of the BPMN are included in the Appendix. Process models were created to facilitate an understanding of the workflow and interactions between different actors and tasks that are involved within the process. These models served as a basis for further analysis of the cases.

After the process models were developed and reviewed by the healthcare and facilities management professionals, Failure Mode and Effects Analyses (FMEAs) were undertaken. The FMEAs were done to both offer variations of the related failures to the base cases and draw links from those failures to their effects on the healthcare delivery system. These health system effects include both disruptions to clinical operations and threats to patient safety. As an example, an excerpt from one of the FMEAs is included in Table 2.

Table 2: FMEA Example

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 Occurance	Detection Method	Likelihood of Detection	Severity	Actions to Reduce Occurrence of Failure
100.01	HVAC Airhandler	Chiller supply line leak over janitor closet	Leak at fitting/oxidation 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 pinhole 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

The FMEAs are linked to functional block diagrams for the item number and item title. These items are part of the larger systems that were examined. For each item, the “Potential Failure Modes” were listed with an associated cause and effects to the facility. The “Facility Failure Effects” list effects on clinical operations. The “Health Failure Effects” list the threats to patient safety associated with the potential failure. High, medium, and low were used as levels for the “Likelihood of Occurrence,” “Likelihood of Detection,” and “Severity” instead of numbers of 1-10, because a less granular ranking serves the purpose to understand the priority and probability of something happening and having a negative effect. Threats to the patients that were determined from the FMEAs ranged from patient discomfort to the possibility of an infection. Example FMEAs are included in the Appendix.

To further gain a process understanding of how different effects occur and what areas of facility management operations can be involved, Fault Tree Analyses (FTAs) were used to extend the FMEAs. The FTAs link the listed failures through the possible and root causes. This leads to a larger data set when organizing a model that links disruptions to clinical operations and patient safety events with facility management failures.

5.2 Review of Healthcare Information Technology Patient Safety Initiatives

Before designing an information framework for managing healthcare facility information related to patient safety events, it was important to understand prior related efforts. This study analyzed AHRQ’s Common Formats and the World Health Organization’s (WHO) International Classification for Patient Safety (ICPS) for their incorporation of facility information in their classification of patient safety events. Areas of expansion for both Common Formats and ICPS to better incorporate facility information were also identified during the study.

AHRQ’s Common Formats (AHRQ, 2010) and WHO’s ICPS (WHO, 2009) are two initiatives within the health industry to create a common method for reporting patient safety events. The idea of these two formalisms is to have 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. Common Format and ICPS are very 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 facilities and systems within the building would only be categorized under the “Contributing Factors” to the event. The case would be filed as a Healthcare-Associated Infection (HAI) event. Arguably, it would fit better under a separate event type dealing with facilities/maintenance. Research shows that HAIs and other events can be directly linked to maintenance, renovation, and construction (Cooper, et al., 2003). These events may be better suited for future planning if they were categorized within their own event type, such as “Facility/Maintenance.” The ICPS allows for contributing issues to be categorized directly under a “Facility” heading.

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, whereas ICPS can allow for an ever-growing consistent development of this type of better-practices information. An analysis was completed by investigating these two initiatives' ability to fulfill the needs and adequately document case studies. Three case studies were used from literature and industry interviews:

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 a 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.

Table 3 shows the different types of information directly related to the facility that are 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 3: 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. Although 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

The long-term research goals include the development of a model-based system to enable facility managers to improve operations that help 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 having the model-based system serve as a central depository for key facility information. The purposes of this model-based system would be to help in making decisions in a 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). This study was discussed in the paper “Evaluating the Role of Healthcare Facility Information on Health Information Technology Initiatives from a Patient Safety Perspective” (Lucas, et al., 2011), and the abstract can be found in the Appendix.

5.3 Healthcare Standards Review from a Facility Management Perspective

Facilities management within healthcare is responsible for maintaining and sustaining the physical environment to support clinical operations. A review of nine relevant standards listed as important by the American Society of Healthcare Engineers (ASHE) (www.ashe.org) was conducted to investigate the requirements that facility management personnel within the healthcare sector need to meet and be familiar with. An analysis was performed to determine gaps between the regulations and standards as well as to determine the ability of existing technologies to adequately support the regulations and standards. The initial analysis took into account regulations from the following agencies:

- Joint Commission – Environment of Care
- National Fire Protection Association – NFPA 101 – Life Safety Code
- Centers for Disease Control and Prevention – Guidelines for Environmental Infection Control in Health-care Facilities
- Centers for Medicare and Medicaid Services – Conditions of Participation
- Occupational Safety and Health Administration
- Environmental Protection Agency – Clean Air Act, Clean Water Act, Medical Waste Incineration, and Underground Storage Tanks regulations
- Food and Drug Administration – food, drug, and medical equipment regulations
- American Institute of Architects (AIA) – Guidelines for Design and Construction of Health Care Facilities

– United States Pharmacopeia (USP) – USP 797

In addition to these standards and regulations, the International Code Council's International Building Code (IBC) was also included in the review. The IBC was included because of its importance in the design, renovation, addition, expansion, and repair of facilities.

The initial analysis allowed for an understanding of what each regulation and standard covered and how it is related to the operation and performance of healthcare facilities. The second analysis compared the ability of different codes to cover the design/construction and operation/performance of healthcare facilities. The design/construction codes are the IBC, AIA, and NFPA codes, whereas the other standards and regulations deal with performance and operation. The completed analysis concluded that, in general, the design/construction codes adequately support the performance and operational standards/regulations. The area where there seems to be a gap is in electrical design. Even though electrical codes were not specifically reviewed for the comparison, the AIA and IBC do not have anything special when it comes to electrical supply for medical equipment. Operational standards and requirements ban the use of extension cords and power strips unless they fit under strict specifications to meet a "hospital-grade" requirement. With the amount of equipment and technology that are required to be plugged in at a certain area around the bed of a patient, the standard electrical requirements fall short. This had also been noted as a problem during interviews with hospital facility management staff.

Another gap that can possibly affect design is that there was no guidance on the design of medication compounding rooms in the AIA or IBC. This is covered in the USP 797, which may not be known to an engineer or designer. If a designer is familiar with healthcare standards and the hospital administration is part of the design team, this should not be missed. However, going from a strict "design code" point of view, the gap does exist. This study was described in the paper "Gap Analysis of Guidelines' and Standards' Ability to Support Performance of Healthcare Facilities," and the abstract can be found in the Appendix.

5.4 Ontology for Healthcare Facility Information

As a conclusion to the previously listed studies, the links and needed information to support the links between facilities management and patient safety were examined to develop a high-level ontology or classification framework for managing healthcare facility information. This study utilized use case analysis, based on the previously developed case studies and FMEAs, to determine information relevant to completing facilities management tasks that have a patient safety aspect. The use cases were also used as a basis for the framework development.

The framework's data model was created using the case studies as a basis for information types. These information types were examined at a high level to create the overview data model shown in Figure 1. The main goal of the data model is to connect elements of the facility that are under the supervision of facility management personnel to patient safety events. The data model has a polymorphism design, in that it is not linear to start with a patient safety event, a failure, or a piece of the facility. The data model can connect a failure of a component of the building to potential health threats, or a patient safety event that has a certain health threat can be connected to recorded failures.

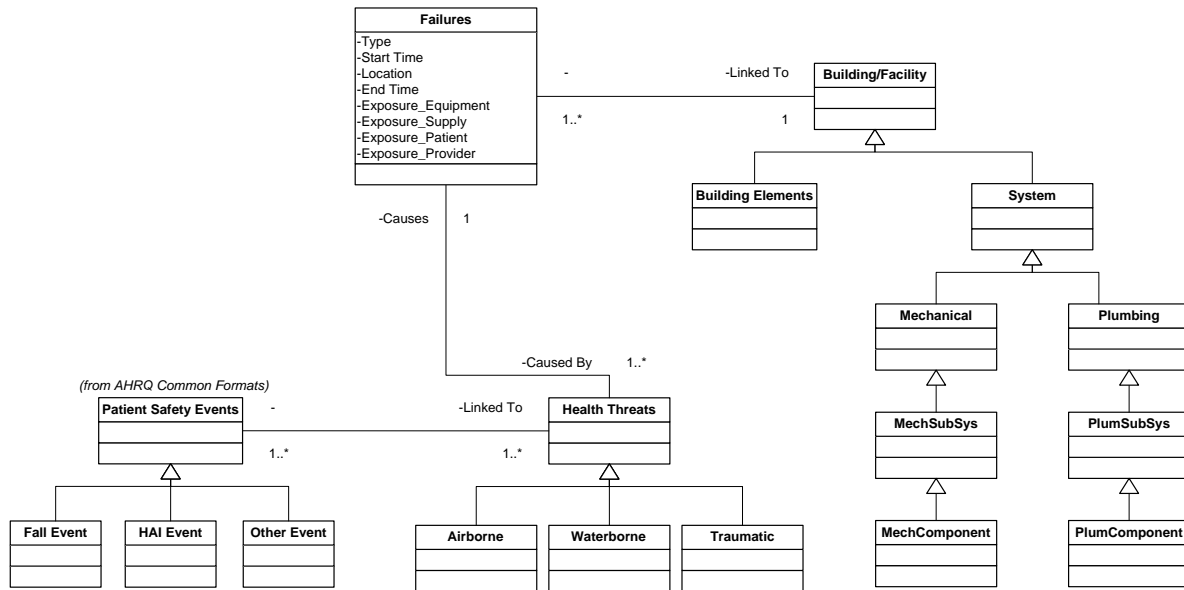


Figure 1: Data Model Framework

The data model is set up with four main classes: *Patient Safety Events*, *Health Threats*, *Failures*, and *Building/Facility*. The *Patient Safety Events* would be classified similar to AHRQ’s Common Format, as reviewed in a previous study. Only sub-classes of *Fall Events*, *HAI Event*, and *Other Event* are included, because they are the only event types within Common Format that have any possible relation to the facility. *Patient Safety Events* only have a relationship to *Health Threats*. Any one *Patient Safety Event* can be related to one or more health threats.

Health Threats are classified with sub-classes of *Airborne*, *Waterborne*, and *Traumatic*. *Airborne* and *Waterborne* are bacteria- or fungus-based pathogens that can cause infections or other physiological problems. *Traumatic* are problems such as slips trips or falls. *Health Threats* have a relationship with *Patient Safety Events* and *Failures*.

The *Failures* class documents the failures that have been recorded. The *Failure* class has attributes of what type of event it was, the beginning (or reported) time and date of the event, and the end time. It also has attributes of exposure to equipment, supply, patient, and provider. The *Failures* class has relationships with both the *Health Threats* and *Building Facility* classes. Each *Failures* incident is connected with one or many possible *Health Threats*.

The last class is the *Building/Facility* class. The inheriting sub-classes of the *Building/Facility* class are *Building Element* and *Systems*. The *Building Element* sub-class consists of items like walls, doors, floors – physical elements of the building. The sub-class *Systems* is broken down into sub-sub-classes of *Mechanical* and *Plumbing*, each of which has another sub-class for sub-system and then component. Each *Building/Facility* incident has a relationship with one or many incidents of the *Failures* class.

Conclusions, Significance, Implications

There are several conclusions that can be drawn from this pilot study:

- a) There is a strong link between facilities management activities and the healthcare delivery process, and these sometimes pose a risk to patient safety. A number of facility failure incidents were identified, and the role of facilities management personnel in resolving these and minimizing the risk to patient safety was highlighted.
- b) There is scope for proactively minimizing patient risk by monitoring critical facilities to ensure that problems are caught and addressed early. In this regard, the use of sensors and other appropriate instruments is considered necessary.
- c) Effective communication links between the healthcare facility management personnel and the clinical personnel are very important in avoiding and minimizing the impact of facility failures or incidents.
- d) Existing standards and guidelines for facility works in hospitals make some references to the role of the facility in healthcare delivery. However, there is a need for more explicit categorization of facility-related patient safety information so that particular attention can be paid to these.
- e) The costs associated with facility failures can be considerable. In addition to the direct financial loss in resolving the problems that occur, other costs include delays and disruption to healthcare delivery processes, the diminished quality of service to the community served by the healthcare facility, etc.

The findings outlined in this report are **significant** in that they establish that there is a strong link between facility management information and healthcare delivery processes, which is worthy of more detailed investigation. They also demonstrate that there are significant potential benefits in understanding better the role that the 'environment of care' plays in the healthcare delivery. The findings also have important **implications** for all stakeholders in healthcare facilities. In particular, it is important that the environment of care is well maintained and adequately supports the healthcare delivery process. Given the exploratory nature of the study, many emerging issues could not be addressed during the course of the study. Thus, there are numerous research issues that should be tackled in follow-on research projects. Some of these are briefly discussed below:

1. Investigation of mechanisms for tackling and resolving facility-related patient safety problems;
2. Investigation of the degree to which the healthcare facility management activities contribute to healthcare-associated infections (HAIs);
3. The cost impacts of facility failures on the healthcare delivery process;
4. Development of measures to minimize facility-related patient safety issues during the retrofitting of healthcare facilities;
5. Human behavior issues in facility-related patient-safety problems;

6. The development of lifecycle ontology-based Building Information Models for the management of healthcare facility information;
7. The role of modern information and communication technologies in improving the detection, notification, and resolution of facility failures.

The graduate students that worked on this project are building on the outcomes of this study by pursuing two of the above topics (Nos. 4 and 6) as part of their doctoral studies. The HAI research topic (No. 2) is the subject of an R18 proposal being prepared by the research team for submission to AHRQ in the next proposal submission round.

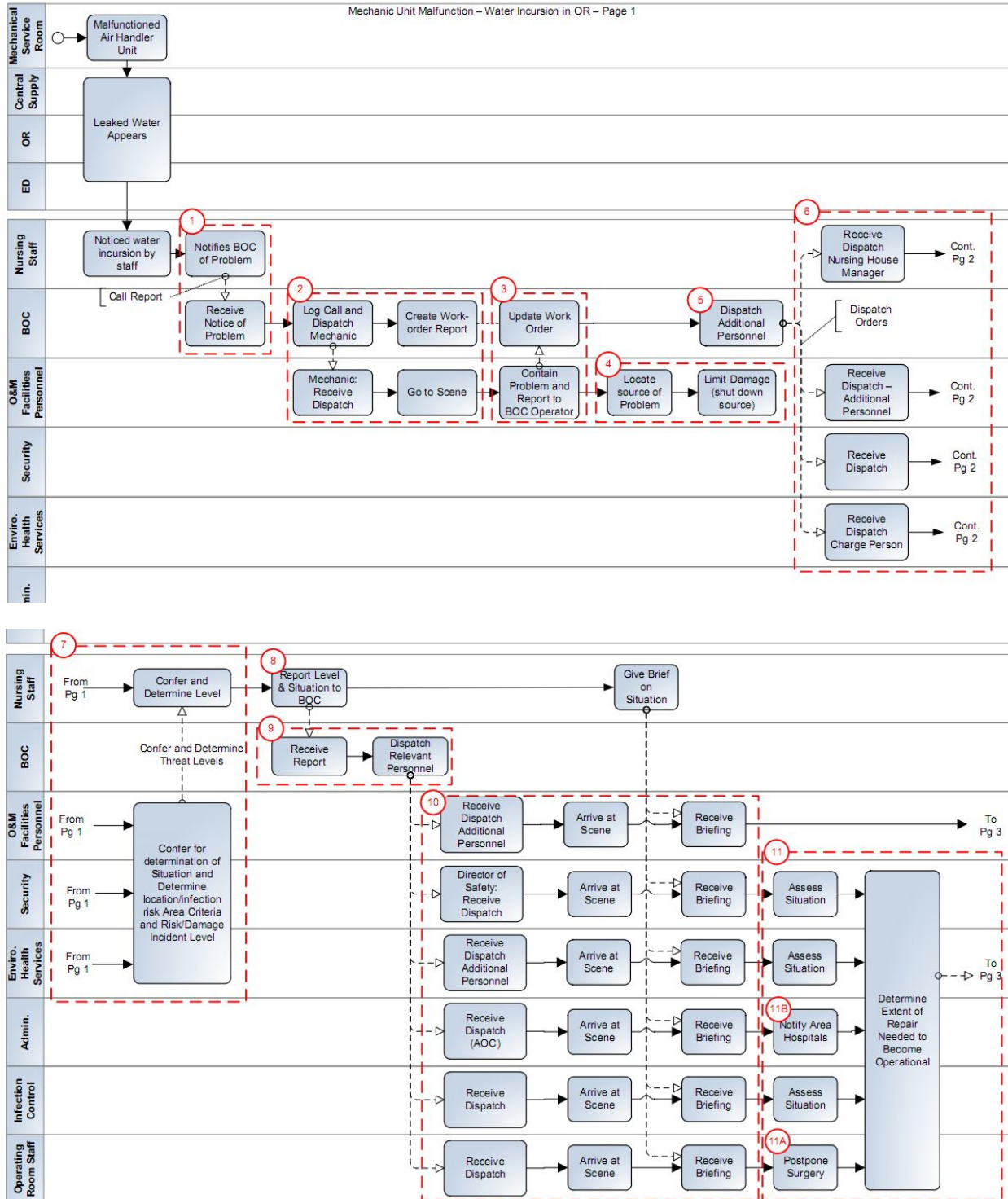
6. LIST OF PUBLICATIONS AND PRODUCTS

Several publications have resulted from the project and are listed below. Papers that have been prepared for publication are also included and clearly described as such.

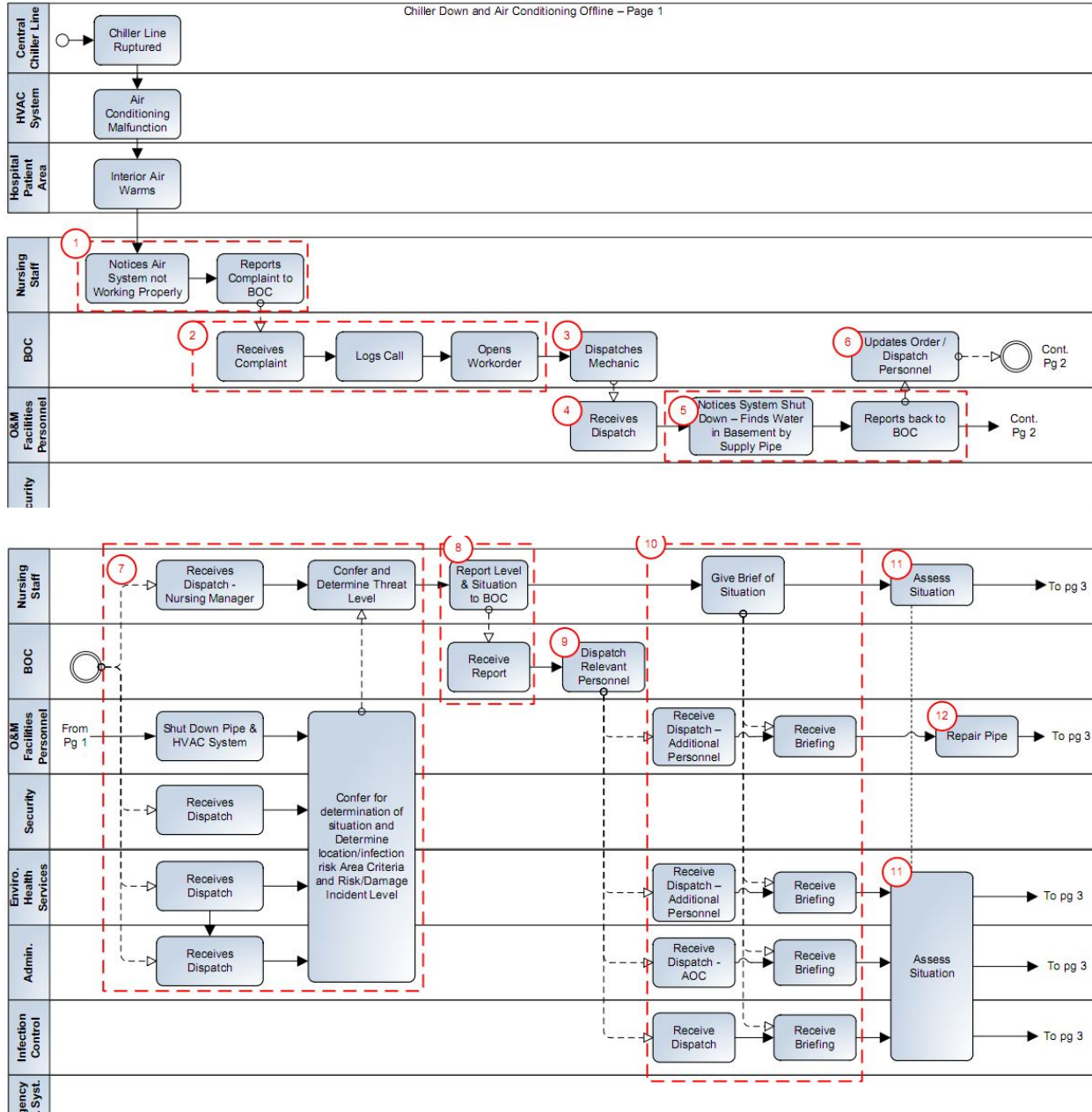
- a) Lucas, J., Bulbul, T., Anumba, C., Messner, J. (2011) "Evaluating the Role of Healthcare Facility Information on Health Information Technology Initiatives from Patient Safety Perspective" in Proceedings of the ASCE International Workshop on Computing in Civil Engineering, Y. Zhu, R.R. Issa, Editors, ASCE, Reston, Virginia, pp. 720-727.
- b) Lucas, J., Bulbul, T., Anumba, C., Messner, J. "Gap Analysis of Guidelines' and Standards' Ability to Support Performance of Healthcare Facilities" (to be submitted to ASCE Journal of Performance of Constructed Facilities).
- c) Lucas, J., Bulbul, T., Thabet, W., Anumba, C. "Case Analysis to Support Healthcare Facility Information Management System" (to be submitted to Automation in Construction).
- d) Lucas, J., Bulbul, T., Thabet, W., Anumba, C. "An Ontology for a Model-Based Support System for Facility Management of Healthcare Facilities" (to be submitted to Automation in Construction).
- e) Mohammadpour, A., Anumba, C.J., Bulbul, T., and Messner, J.I. "Integration of Facilities Information and the Healthcare Delivery Process" (in preparation for presentation at the 2012 Construction Research Congress, May 21-23, 2012 at Purdue University, USA).
- f) Mohammadpour, A., Anumba, C.J., Bulbul, T., and Messner, J.I. "A Taxonomy for Requirements for Energy Efficiency in Healthcare Facility Retrofits" (in preparation for presentation at the 2012 Innovation in Architecture, Engineering and Construction Conference, Sao Paulo, Brazil).

APPENDIX

1. Partial process model for malfunctioning HVAC unit in OR



2. Partial process model for chiller pipe burst/air conditioning shutdown



3 Partial FMEA for Air Conditioner over Patient Rooms

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 possibility 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 possibility 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 possibility 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 possibility 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 possibility of occurrence
120.02			blockage in coil due to mineral build-up	air temperature and humidity 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 possibility 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 controlled 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 possibility 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
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 possibility 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 possibility of occurrence

4 Partial FMEA for Mechanical System over Operating Room Suite

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 Occurance	Detection Method	Likelihood of Detection	Severity	Actions to Reduce Occurrence of Failure
100.01	HVAC Airhandler	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 cooridor	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
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 uneffected 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

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	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 cooridor	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
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 scnsor	Medium	High	Regular maintenance of systems and training to report cases as soon as something is noticed

5. Publication Abstract

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.

6. Publication Abstract

Gap Analysis of Guidelines' and Standards' Ability to Support Performance of Healthcare Facilities

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ABSTRACT

The condition of the physical environment within healthcare facilities has a large impact on the quality of care, recovery time, and patient satisfaction. In order to maintain and ensure adequate operation and performance of the physical environment, facility management must maintain a state of continuous compliance or constant readiness. The facility management personnel must have an understanding of the regulatory standards and guidelines for operating a healthcare facility. This paper discusses an analysis of the major healthcare standards and guidelines that the American Society of Healthcare Engineers (ASHE) suggests facility management groups need to be familiar with. A gap analysis is performed to identify gaps between the design and construction guidelines and their ability to support healthcare facility operation and performance standards. Last, information technologies and building control systems are examined in their ability to help support operation and maintenance of the facility in keeping track of the requirements in reviewed guidelines and standards.

		Topic Area													
		Safety & Safety Management	Security	Hazardous Materials/Waste	Emergency Management	Fire Safety	Medical Equipment	Utilities	Housekeeping	Design	Construction/Renovation	Medication Safety	Food Safety	Infection Control	
		<i>(No. of Sub-topics)</i>													
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/Construct	AIA Document			2	2	6	2	4	2	10	1	7		4
		NFPA - Life Safety Code					5				6				
		IBC					5		1		23	2			