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Development of Integrated Modelling Methods for Supporting HVAC Maintenance in Healthcare Centres

Master thesis

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By

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Topic:

Development of integrated Modelling Methods for Supporting HVAC Maintenance in Healthcare Centres

Hospitals carry out crucial services which mainly include taking care of sick patients with health vulnerabilities, thereby making clinical operations rely heavily on certain building facilities to optimize their primary role as care-givers. Facility Management personnel are now vested with the responsibility to ensure that the environment within the health centre is maintained efficiently. However, information exchange between clinical operations and facility management activities has always been a challenge especially in a situation where facility concerns arise that could have enormous consequences on the healthcare Centre.

Therefore, mechanical issues such as the malfunctioning of an HVAC - Air Handling Unit (AHU) Supply Fan might result to inappropriate indoor air condition which can lead to air borne infection due to the presence of pathogens within the operating room thereby, negatively impacting on both staffs and patients alike in that environment. On this note, the aim of this research work is to explore ways in which innovative modelling methods such as BIM, FMEA, BPMN, and UML could be utilized to support HVAC maintenance in a Healthcare Centre. Further research questions were posed and hoped to be answered in the course of this project.

- How can Facility Managers use Building Information Modelling (BIM) to identify HVAC spatial problem zone(s) and the possible problem causes within a healthcare building environment?
- How can the possible HVAC problem be detected from a failure mode and effects analysis table (FMEA)?
- How can the corrective maintenance response be captured by a Business Process Modelling Notation (BPMN)?
- How is UML Use-Case diagram used to ascertain the facility information requirements for HVAC maintenance in healthcare centres?

This study would include literature reviews to explore impacts of Facility Management information requirements in the healthcare sector in such a manner that the named well-known Modeling Methods will be combined with an optimized workflow to leverage maintenance of HVAC systems in Facility Management. The sole aim of this research is to fulfill the masters' graduate program in Construction and Real Estate Management at HTW Berlin and Helsinki Metropolia University of Applied sciences. More so, this could serve as an added knowledge to the field of facilities management and possibly provide a pathway for further research.

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ABSTRACT

Facility Management uses buildings information to run its operations effectively. This is as true for healthcare buildings for its complexities, which requires total involvement of facility management expertise to keep the clinical environment conducive, for a faster healing process of patients and staffs alike. Therefore, Facility managers in healthcare environment require certain facility information that would assist them in the smooth running of daily activities since, the information of the buildings earlier lifecycle is usually broken down into several phases. Therefore; this research aims to explore developed modelling methods such as Building Information Modelling (BIM), Failure Mode and Effects Analysis (FMEA), Business Process Modelling Notation (BPMN) and Unified Modelling Language (UML –use cases) that can support Facility Management personnel to address healthcare HVAC facility problems, while highlighting information communication exchange between clinicians and facility management staffs.

The early chapters deal with introducing the work and stating the research problem which had to do with temperature increase and odour in the operating room. Subsequently, modelling methods were explored to ascertain the information requirement designed to support facility managers. BIM was used to obtain the problem location and root causes of the problem, FMEA was applied here to examine the severity of the threats it poses to patients and clinical staffs, BPMN approach was done to show how the corrective maintenance can be carried out and UML diagrams analysis were used to ascertain information required to support Facility Management in addressing problems.

Conclusively, the result of this research work indicated that information requirement includes the Use-Case scenarios, the steps within the Use-Case scenarios, the actual activity/phase that takes place within the scenarios, the user responsible for facilitating the activity/phase and lastly, the source where the responsible user should get the information about the activity/phase within the scenarios. All these information goes to support the Facility manager to determine a quick form of response, knowing the parties that are involved in each step all the way.

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LIST OF ABBREVIATIONS

AEC	Architecture, Engineering and Construction
AHU	Air Handling Units
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BIM	Building Information Modelling
BPD	Building Process Diagram
BPMN	Business Process Modelling Notation
FMEA	Failure Mode and Effects Analysis
HVAC	Heating, Ventilation and Air-Conditioning
GUI	Graphical User Interface
IFC	Industry Foundation Classes
IAQ	Indoor Air Quality
OMG	Object Management Group
SBS	Sick Building Syndrome
UML	Unified Modelling Language

Chapter One

1. Introduction

1.1 Background

Hospitals carry out important primary services which mainly include taking care of sick patients and as such they heavily rely on certain building facilities to optimize their primary role as care-givers. Facility personnel's are now vested with the responsibility to ensure that the environment within the health centre is maintained efficiently. Therefore, the ability for facility management team to be able to support in certain areas such as providing a safe working environment has proven to influence the way, and manner care-givers or healthcare staffs do their job more effectively. Similarly, (Lucas, 2012) defines a clinic from a facility management perspective as a complex and dynamic system in which all spaces, building components, and assets are all related to each other. Additionally, the movement of people and goods within the healthcare environment further shows close links between healthcare building facility information and the buildings facility content. That is, facility content here could mean every component in the building fabrics that contribute in one way or the other by interacting with healthcare workers as well as patients' well-being. These contents include the heating, ventilation and air-condition (HVAC) systems, Medical equipment, electrical systems, plumbing and so on. Therefore, the scope of this research work would be based on HVAC building facility content. The main aim of this paper is to critically examine the need to create rich integrated facility information requirements that can be immensely populated with information capable of transforming the way facility management teams' plan, program and respond to their HVAC facility maintenance. These information requirements could be used as a basis to structure a product model into an outright development of facility application used in solving facility management related issues. This paper seeks to find comprehensive information in terms of HVAC related problems occurring in healthcare facilities. It would also identify the Building Information Modelling (BIM) data whilst creating links between clinical information and facility management information. In addition, this research would explore corrective interventions used to mitigate against potential failures that will be identified using a Failure Mode and Effects Analysis (FMEA). That is, this research work will examine developed modelling methods; that facility managers could leverage to support HVAC problems in healthcare centres.

1.1.1 Healthcare Physical Environment

The truth is that healthcare environment can pose health hazards to the patient and this has been troubling. Following this, (Verde, et al., 2015) claims that airborne micro-organism can originate not only from humans (also patient) but can be spawned by various indoor hospital characteristics and outdoor air environmental sources. The physical healthcare environment should be a place that is meant to speed up a healing process for in-patients, however; this could actually be the reverse case. 'Health associated-infections (HAIs) such as infections caused by methicillin-resistance staphylococcus aureus (MRSA); or infections of the surgical sites or operating rooms, urinary tract or bloodstreams - are a major healthcare problem (Clancy, 2013) Clinical staffs have always felt that this will continually be a healthcare problem (Job/environmental hazard) that has come to stay in the healthcare industry. However, there have been things put in place to mitigate this health associated infections in recent times. Fortunately enough, since these healthcare associated infections could be averted, (Clancy, 2013) further stated that clinical stakeholders should examine every care aspect of the care environment to ensure that best efforts are applied to ameliorate patients' exposure to potential hazards. This goes to reflect that the air filtration system in a ventilation process can drastically help to reduce the transmission of pathogens which are the root causes of healthcare associated infections. As rightly stated by (Clancy, 2013) "that healthcare leaders must look around their own physical environment with the goal of ensuring that hospital buildings contribute to the fast recovery of patients rather than impede on the healing process". In addition to this, hospitals may be impacted by seasons, weather conditions, indoor air ventilation system design and operations, intrusion of moisture, outdoor microbial load plus number of occupants, visitors and activities due to its ever changing environment (Park, Yeom, Lee, & Lee, 2013). This in itself has shown to be a great challenge to healthcare professionals as it has been a daunting task to overcome the issues of microbial growth of indoor air quality. This underscores the very reason for having an HVAC system in the healthcare industry; proven to be important going forward. That being said, it is quite of enormous importance to reiterate that the healthcare environment is quite a complicated place due to its nature of activities mostly driven by the sick and vulnerable people with health concerns. This in its entirety has made the healthcare environment a place that is worthy of looking into.

1.1.2 HVAC Importance in Healthcare Industry

Heating, ventilation and air-conditioning installation control indoor air quality and aseptic conditions, and secure healthy, safe and suitable indoor thermal conditions for surgeons, medical staffs and of course the patients, (Balaras, Dascalaki, & Gaglia, 2006). They also went further to argue that the air in Operating rooms must be aseptic at a reasonable constant temperature and humidity, and have relatively low velocity to prevent drafts and swirls that promote the recirculation of microbes which may disrupt the procedures during an operation. The integral HVAC system is made up of the Chillers, Air Handling Unit (AHU) and Ventilators. But maintaining the scope of this research, the AHU system would be concentrated on. The very essence of HVAC system in the hospital is to ensure that the atmosphere within the fabrics of the building is such that fosters quick recovery amongst patients whilst providing the right working conditions for staffs. As explained earlier, a malfunctioning HVAC in a hospital can lead to further conditions due to the reproduction of microbes in form of moulds in which, constant inhalation could be disastrous for both workers and patients alike. So far, it is noticed that the healthcare environment does have lots of downside with respect to the possibilities of infections and here, HVAC systems would help in addressing any possible issues that might impose future threats to patients and nursing staffs as related to air borne pathogens within the healthcare environment.

1.1.3 HVAC maintenance cost

It cannot be over-emphasized that HVAC plays an important role in the smooth running of hospitals. However, this obviously comes with cost implications. The provision of detailed cost breakdowns for repairs, replacement, and maintenance of HVAC systems in a complete and acceptable format as stated in *Ashrae's means 2002A* HVAC life cycle cost source data, (Krus, 2004). He further noted that maintenance cost is usually tracked from the cost of maintenance contract, which accurately expresses the current market value for maintenance jobs within a geographical area. On the contrary, this does not usually reflect the real cost of job that is performed during maintenance activities. As it is known already that the cost of operational life of a facility is much more than the design and construction phase, this has made the maintenance of HVAC equipment very important. “A reasonable range for HVAC maintenance and material cost would be 1.4% - 10.2% of plant replacement value. For instance, the initial cost of HVAC in a 55,000 square foot hospital of 740,000 dollars, the annual maintenance cost should be 10,000 – 75,000 dollars or between 0.19 per square foot and 1.37 dollars per square foot (Krus, 2004)". The failure of a medium to a large sized coil in an HVAC system typically requires several days to replace once a suitable coil has been located and procured, (Piper, 1995). The writer further argues that replacement costs, particularly in installations where no provisions were made for coil replacement in the Air Handler design, often approach the original cost of the Air Handler. This actually underscores the importance of adequate maintenance of HVAC system coils within a building and healthcare centers are more delicate and complicated in this respect. From the above stated sections, it can be deduced that HVAC systems are quite important as they are vested with the responsibility to carry out the cleaning of air pathogens from the environment in a bid to reduce the increase of infections within the surrounding. In this regards, there seems to be a correlation between the level of work done by HVAC systems and the cost of maintenance. That is, since HVAC systems are usually on the run almost every day to keep the air quality standard at an optimum level, a constant level of maintenance must be applied as well to keep up with the demands. Hence, this would have a direct impact on financial outlays.

1.1.4 HVAC-BIM Challenges

One common challenge with HVAC maintenance operations and BIM is to get certain information that could be utilized by facilities management teams effectively. HVAC maintenance related issues would be a lot easier to tackle if the components that make up the HVAC systems are well known and identified, (Xue & Ergan, 2015). This apparent challenge is because the industry standard for interoperability is IFC 2x3 which does not specify which subtype or function an HVAC component is even though they are of the same type. For instance, HVAC system has several parts like dampers, coils, valves and fans. Each of these parts has their different components with divers' functions. However, Industry Foundation Classes (IFC) files in BIM do not differentiate these functional components. In this case, facility teams might find it a daunting task to locate which of the components is failing and needs to be maintained. That being said, it is obvious that facility managers are sometimes faced with the challenges of differentiating HVAC components in BIM; in order to carry out efficient maintenance of HVAC system serving the healthcare environment. This research establishes ways that HVAC – BIM details can be identified in such a manner that can enable the facility manager to locate the exact component and precise location.

1.2 FMEA and BIM Application for HVAC Maintenance

According to (Hampl, 2010), failure mode and effects analysis (FMEA) is a bottom-up technique used to identify, prioritize and eliminate potential failures from the system, design or process before they reach the customer. Going back to history, FMEA originated as a military procedure tagged as MIL-P-1629 and published on the 9th of November 1949 and was titled procedures for performing failure modes, effects and critical analysis. It was further used in the aerospace and rocket industry in the mid-1960's. Down the line in 1974, it became the military standard known as MIL-STD-1629. This also explains the five (5) types of FMEA which are concept, design, process, service, and software FMEA's. Although with slight differences in their approach, these types of FMEA's are geared towards identifying and eliminating potential failures to a system, product or service and HVAC products are one that should enhance the level of services in healthcare industry thereby impacting the customers in a positive manner. Additionally, (Hampl, 2010) also noted here that FMEA's are used in identifying critical or hazardous conditions, potential failure modes, need for fault detection and effects of the failures. Going by the HVAC issues that might impede on the integrity of indoor air quality in hospitals, facility management professionals have decided to use the FMEA as a tool to address potential failures of mechanical systems and also the threats that abound when these failures occur. In addition to this, corrective measures to combat these failures are equally ascertained in using this tool that is most common in the automobile industries alike.

As the term connotes, BIM which means building information model is a recent concept in the Architecture, Engineering and Construction (AEC) industry and whose potential is yet to be harnessed. This information in a BIM model is simply the coordination of all information from the design phase and through to the construction. Finally, this information is usually transferred to the operations and maintenance phase. Following this, (Xue & Ergan, 2015) who stated that BIM had been used to facilitate the information exchange through the life cycle of a building which includes, the facility management phase. BIM application for HVAC maintenance, especially in the healthcare industry cannot be over emphasized because it has a lot of contributing factors in facilitating the way and manner in which corrective maintenance is carried out. This includes the reduction of time for repairs by technical mechanics in solving the possible fault that may have occurred with the HVAC equipment for operating rooms. BIM has lots of benefits that are abounding for the facility manager to utilize; however, the great potential may not be realized if not effectively communicated during the lifecycle of the building. Efficient information exchange from BIM to other stakeholders of an environment is essential when certain facility related problem arises.

1.3 Problem Statement

It is a common trend that facility management and clinical staffs do not share critical information that needs to be used interchangeably. This information includes facility systems that aid clinical staffs to carry out their primary purpose of activities such as taking care of patients’ health status successfully. The need for an efficient HVAC system to be in place in a surgical/operating room should be well communicated to facility management teams in a hospital. Most times, there could be mechanical issues with HVAC - AHU that might result to inappropriate indoor air condition which can lead to air borne infection within the operating room thereby negatively impacting on the health of both staffs and patients alike in that environment. In a situation where this is not swiftly communicated to facility managers, a lot of time is lost before the actual issue is ascertained and that could be disastrous to the reputation of the hospital.

In addition to this, it is directly proportionate to the cost of maintenance. In a situation where facility managers do not have a proactive approach to addressing problems such temperature and atmospheric issues in the operating room, is in itself an impediment to the optimum safety of the patient, health workers and general reputation of the hospital or healthcare centre. Therefore, one major problem this research seeks to solve is the information gap between clinical staffs and facility management personnel in addressing healthcare facility issues or concerns. In bridging the gap, an integrated facility information requirement would be used to solve an HVAC – AHU supply fan failure thereby applying several methods to describe how these methods could support facility managers in their operations.

1.4 Research Questions and Goals

- How can facility managers use BIM to identify HVAC spatial problem zones(s) and possible problem causes within a healthcare building environment?
- How can the possible HVAC problem be detected from a failure mode and effects analysis table?
- How can the corrective maintenance response be captured by a Business Process Modelling Notation (BPMN)?
- How is Unified Modelling Language (UML) Use-Case diagrams used to ascertain facility information requirements for HVAC maintenance in healthcare centres?

The precise goal of this work is to ensure that all the above stated research questions are answered accordingly. Thereby creating integrated facility information requirements for supporting HVAC maintenance in healthcare centres. These questions would be addressed by the use of methods which include building information modelling, Failure Mode and Effects Analysis, Business Process Modelling Notation and lastly Use Case Diagrams which will be done with a Unified Modelling Language (Eclipse 2.0) application. These methods would be use an integration approach to reach the goal of the creation of information requirements that could be utilized by facility managers to take decisive actions on facility related problems. It could also be used to build a product model or Graphic User Interface (GUI) application in a further research. That means, this approach forms the basis for any further product model that can be created as it would be adequate to support facility management operations in the long run.

1.5 Organizational Structure

Chapter One

In this chapter, the researcher simply looks at areas that are of concern to the research topic such as healthcare environment and how facilities management integrates to the activities of the hospital operations to make the primary goal successful. There are certain areas in the healthcare environment that could affect the primary goal of rendering successful nursing care for patients which includes the area of HVAC components that can impose enormous threat to the lives and safety of stakeholders in the healing environment like hospitals. Problems like poor indoor air quality within the operating room of a hospital can cause serious issues to the safety and well-being of patients and staffs which is attributed to the mechanical systems like the HVAC systems meant to mitigate the effects of this problem occurring. Conclusively, this chapter outlines the problem of information exchange between the healthcare workers like clinicians and the facility management operations as information are always fragmented during the lifecycle of a facility. In solving these issues of information exchange within the healthcare industry, this chapter emphasized the fact that an integrated facility information requirement would be the appropriate approach to bridge the gap and this was reflected in a case study. Indoor air Pathogens in an operating room strive the most where the ventilation systems go bad and this could increase the risk of infections on surgical patients. On this note, this research tends to find out the possible causes of AHU fan failures and the steps that have to be done to mitigate problems of similar magnitude in the future. Further research questions were posed and hope to be answered in the course of the project.

Chapter Two

Having known the challenges that has to do with information exchange between clinical operations and facility management operations that was explained in chapter one coupled with the problem of a malfunctioned HVAC - AHU supply fan, this chapter two explains the precise approaches that could be applied by facility managers to correct the problem before it further degenerates into something worse. These approaches are considered to be modelling methods that were used in an integrated manner to harness healthcare facility information requirements that would support facility managers in mitigating HVAC maintenance issues within the healthcare environment. These methods include the following: Building Information Modelling whose acronym is (BIM), Failure Mode and Effects Analysis (FMEA), Business Process Modelling Notation (BPMN) and the Unified Modelling Language (UML) Diagram for Use- Case Scenarios. These above methods were used according to a descriptive case study in this research and conclusively, the overall information required supporting facility managers in swiftly correcting similar issues that come up in the distant future. Meanwhile, the information requirement details could be used to develop a full product model or application that is primarily to support facility management activities within healthcare industry.

Chapter Three

This chapter reflects the state-of-the art in terms of several literature reviews where the above methodology was used to address similar problems. Couple with this fact, salient explanations were made as regards terminologies related to this topic such healthcare infrastructure, facility management (FM), HVAC System, FMEA, BIM, BPMN and UML Use - Case Scenario.

The main aim was to achieve a framework that would assist facility managers achieves fluid healthcare facility management efficiency through modelled information architecture (Lucas, 2012). This research exhibited the use of FMEA, BIM and BPMN to create an ontology used to further create the framework that was tested in a particular case study of a hospital.

Moreover, (Xue, 2015) in his research was aimed at forming a framework that helped facility managers identify, retrieve and visualize information that could be used by HVAC mechanics to troubleshoot HVAC related problems. This research was carried out a little differently from Jason Lucas because it seeks to provide the mechanic concise information that can be used to reduce the time for solving the HVAC work order problems. Here, the work order is the base of how all other required information from the BIM would be obtained i.e. space ID; Equipment IDs and so on, which are further used alongside other applications to create a solid information framework that could assist the HVAC equipment maintenance process.

Also, (Shalabi & Turkan, 2016) in his study paper stated how to improve the quality of data collected that is required for corrective maintenance by utilizing visualization and interoperability of building information modelling (BIM). In this approach, BIM data in the form of IFC was linked with other facility management applications such BAS, BEMS and CMMS; then developed in a manner that it was further validated in an educational real estate environment. This application could actually be used in healthcare real estate as well. The result of this chapter is to show literature reviews concerning one or more methods used in this project. Some of the concepts were actually applied to this research topic to give a clearer view of how to address the problem of AHU supply fan malfunctioning in the healthcare centre.

Chapter Four

In this chapter, the researcher discusses how the methods explained in earlier chapters would be carried out in other to satisfy the research questions and meeting the objectives of the project work. The image below depicts what this project outcome is all about as shown. An HVAC failure occurs in the mechanical room thereby causing a high temperature and odour due to the stuffiness within the operating room, having going through the processes of obtaining the cause which was eventually linked to the HVAC supply fan, an FMEA report is drawn up to ascertain the level of threats this failure would have on the occupants (clinicians and patients alike) and also the possible potential causes that may cause such a problem. Going forward, a BPMN diagram would be drafted to reflect how the corrective approach can be carried out with involving participants in each department. Then finally, the UML Use-case scenarios would be made to analysis the approach used earlier in order to obtain the overall integrated facility information requirement that can support facility management operations in healthcare centres. Finally, this information requirement could be used further as a basis to build a product model used in a graphic user interface however; this is not covered within the scope of this research.

Chapter Five

This chapter simply concludes all that have been done so far in this project. It also looks at facility information requirements for corrective maintenance of HVAC systems and most importantly the contributions this approach would have on the healthcare industry. Finally, areas of future research work would also be cited to give some direction for improvement in this area of research.

Chapter Two

2. Descriptive Modelling Methods

The proposed integrated facility information requirements for supporting HVAC maintenance in healthcare centres intend to offer an optimized method for managing information for swift response to issues by facility management staffs as regards HVAC – AHU boundary. For this reason, there is a need to ascertain the necessary information needed to execute and design this structure in response to similar HVAC cases that could occur. Therefore, a descriptive case study process was develop and elaborated to describe the types of information needed to structure the essential information and Ontology that helps to formulate these information management instruments within the framework. This chapter hereby elaborates the case study method used to ascertain the information needed to support and back-up facility management response in respect to the specific problem coupled with the fact that it creates or establishes the relationship between the healthcare information and facility information within this particular case study.

To further delve into the research methods used to tackle this issue, a table is displayed below to reflect the approach according to the research questions. This will reflect in simple terms a clear visualization of the relationship between the questions and their respective ways to support the actualization of their aim in this research. This approach was used by (Lucas, 2012) where he described the various methods applied to solving or meeting each objective in his work and this sought of gives a clarity to understanding the information links to formulating the model used for his project framework.

Table 1: Application of Research Methodology

Methods	**Research Question (i)**	**Research Question (ii)**	**Research Question (iii)**	**Research Question (iv)**
Building Information Modelling	☆			
Failure Mode and Effects Analysis		☆		

Business Process Modelling Notation			☆	
UML Use-Case Diagrams and Scenarios				☆

The above table reflects the approach that would be adopted to design the information requirements that will support facility management personnel to address HVAC issues in operating room. For example, the cases of a faulty supply fan in an AHU of the mechanical room. The analysis of the case study scenario is quite documented in series of approaches and the results of these methods used was to reach a conclusive decision on the very information needed to carry out the appropriate facility management activities in order to maintain the overall goal of the healthcare business by optimizing facility infrastructural support to the primary goal of hospitals.

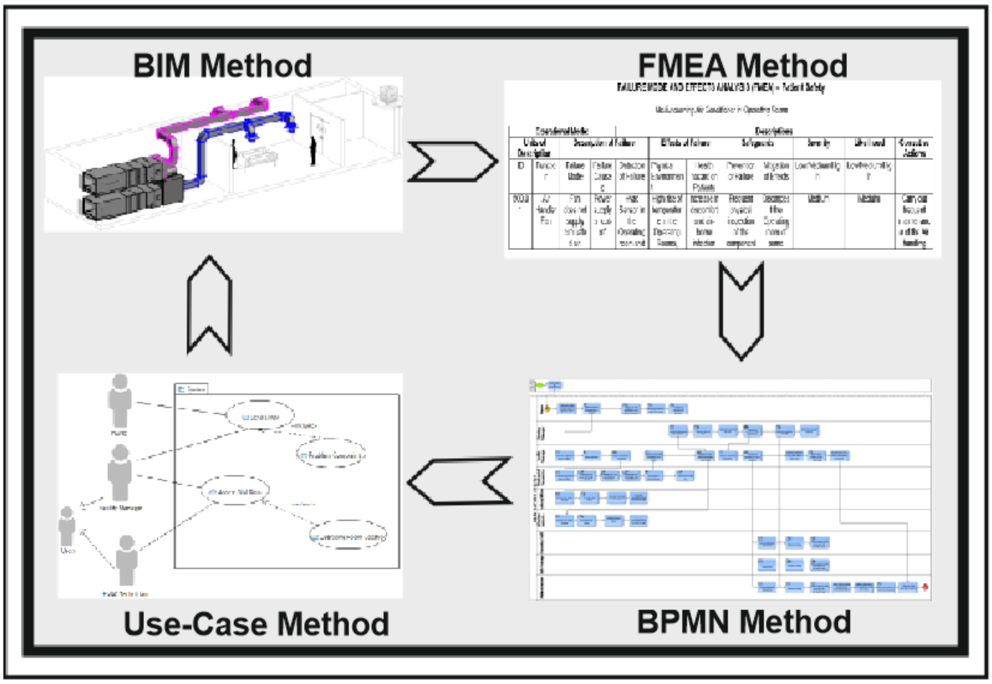

Figure 1: Graphical Representation of Modelling Methods

2.1 Key Definitions

Healthcare Infrastructure

This can be defined as a physical environment where patients go to obtain treatment as it relates to their total wellbeing. This infrastructure have several components which includes visible facilities that makes healthcare accessible especially facility components like HVAC systems. According to (National Air Filtration Association, 2007), states that HVAC system has the job of heating and cooling, adding or removing moisture, and transporting and cleaning the air in a building. Since most buildings newly erected do not have openings like windows that open (same goes for operating rooms in healthcare centres) where only by HVAC systems are the ways of bringing in air into the enclosure; therefore in a case where the systems are not appropriately maintained can invariably be sources of contaminations in this very enclosures. Any faulty part of the mechanical system like the AHU components i.e. filters; coils or even the supply fan could impact the integrity of the air quality in the environment. This could lead to builds up of moulds within the enclosure of the fabrics which in fact could also lead to the famous sick building syndrome (SBS). Nowadays, healthcare centres create lots of indoor air quality concerns as it relate to other similar concerns that are involved with other buildings. Separate rooms or normally called isolated rooms are usually designed in such a way that its air filtration process protects patients. New designs for surgical suites allow for proper air flow patterns and (HEPA) filtration modules at the ceiling outlets as claimed by (National Air Filtration Association, 2007). As it is known that healthcare centres; amongst other types of real estate uses are obviously the most complicated, due to its special areas within the environment. These special areas which include operating rooms as said earlier, needs careful attention to the indoor environmental quality requirements as stipulated by the regulations due to the fact that it has a wide way of affecting both patients and medical staffs that work and spend time within this surgical theatres. According to (Balaras, Dascalaki, & Gaglia, 2006) they stated that about 50 percent of doctors work in the operating rooms, as surgeons or with other responsibilities like (anaesthesiologists), meanwhile about 10 percent of the total medical staffs also work in the operating rooms as well. In respect to this, the heating, ventilation and air condition system within the healthcare centre is very important to control and maintain a proper temperature and humidity within these areas as to mitigate against the effects of microbes generating in their numerous volumes. (Balaras, Dascalaki, & Gaglia, 2006) further stated that an operating room can be considered a clean space with an emphasis on controlling specific types of contamination rather than the quantity of particles present in the air. Therefore, their seems to be a correlation between HVAC facilities (i.e. Air Handling Units) and the quality of air within the operating rooms or specialized zones within healthcare facilities. (ASHRAE, 2013) stated that HVAC can affect the distribution pattern of airborne particles by diluting or concentrating them, moving them into or out of the breathing zones of susceptible persons, or by accelerating or decelerating the rate of growth of air borne microbes. The body further added that improper maintenance of HVAC system could even inhibit more microbes by creating a reservoir for them.

Facility Management (FM)

This can be defined as a profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, process, place and technology (Roper, Cotts, & Payant, 2010). That is, during the operation and maintenance phase, the facility managers ensure that HVAC systems are in a good state of functionality to support the people, in a place, following the a predefined process with certain technology like an information architecture models to facilitate the healthcare service delivery. According to (Shohet & Lavy, 2004), facility management was defined “as the application of integrated techniques to improve the performance and cost effectiveness of facilities to support their organization development”. They further itemized three (3) main paradoxes in previous literatures about facility management which are as follows:

- Facility management is recognized as a strategic discipline, while most of its practitioners are found at the operational levels of their organizations.
- Facility management aims to be at the heart of any organization development, while many facility management services are delivered by external professionals and
- Facility management aspires to manage changes within an organization, while in most cases it is reactive in nature.

Facility management is mainly caught up with the objectives of operation and maintenance of real estate properties in which healthcare is a special kind. In the case of healthcare HVAC maintenance carried out by facility personnel could be in-house or outsourced externally or even a combination of both.

HVAC System Functions

The primary requirement of the heating, ventilation and air-conditioning (HVAC) systems in a medical facility is the support of medical function and the assurance of occupants' health, comfort and safety (Guyer, 2009). In helping healthcare process, the HVAC is usually needed to do several vital functions that affect the environmental status, infection and hazard control, and buildings life safety. According to (ASHRAE, 2013), through the containment pattern, dilution and removal of pathogens and toxins, the HVAC system is a key component of facility safety and infections control. Additionally, HVAC systems should interact with the architectural building envelope in order for the unconditioned air to be controlled, plus external contaminants and moisture. Moreover, it is expedient that the indoor Air environmental conditions should be properly preconditioned due to the sensitive equipment within the healthcare special areas and are very crucial to the healthcare service delivery. These perhaps include special imaging systems, IT support systems, healthcare electronic data storage, critical medical equipment and lots more.

Failure Mode and Effects Analysis (FMEA)

This is simply a procedure for identifying, prioritize, and eliminate potential failures from the system, design or process before they reach the customer, (Hampl, 2010).

From the acronym as shown above, this was a concept which originated from the US military that reflects a procedure that later became a standard solely for the purpose of detecting failures in systems which HVAC is a considerable product within the healthcare environment (especially in Operating suites) that could assist in the swift recovery of patients. That is to say, it is a way of proactively and systematically goes through your processes, products, or services in order to identify, analyse, prioritize and document potential failure modes. In the sense that, it is aimed to identify ways processes, products or services could fail. And to further understand the effects those potential failures could have on your customers (patients and medical staffs alike) and what those potential cause failures are. As such, if the potential causes are successfully identified, then obviously ways to improve the processes, products or services would likewise be identified in order to reduce the occurrences of those failures. Therefore, FMEA is a methodology to recognize and evaluate potential failure modes in our products, processes or services. Additionally, the aim of implementing this methodology is to mitigate, reduce or eliminate this potential source of failures. This could be seen as a preventative-approach tool meant to be proactive than reactive in nature. This could important to implement as we are developing a new process, products or services. Similarly, a generic approach to carrying out an FMEA is embedded in the following ways:

- Identify and anticipate potential failures
- Identify potential causes
- Prioritize the potential failures and
- Reduce, mitigate or eliminate the failures.

Meanwhile, according to the (American Bureau of Shipping, 2015) failure mode and effects analysis states that it is a design and engineering tool which analyses failure modes within a system to determine the impact of those failures.

Building Information Model (BIM)

This is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from the earliest conception to demolition, (National BIM Standard - United States, 2012). This actually serves as a repository with essential information which could be in form of as-built documents and can be modified by all stakeholders in the phases of the facility life-cycle. In a simpler term, it is a process of working together to design, construct and maintain a building and all its components put together. And this is done with mutual exchange of data resulting into a digital description of a building project. From this way, a digital model is made from a standardized object library. This object library could be seen as a dictionary for all objects in the model which should explain the definitions (what do we mean by window, HVAC system etc.), functions (properties) and performance (what must these object be able to do?). In fact, BIM could be used for an entire lifecycle of a construction project.

Business Process Modelling Notation (BPMN)

This is a graphical notation for describing business processes (Software AG, 2014). They further said that the notation id required to be easily understood by all its users. This makes it suitable not just for only business analyst and those who monitor and manage processes but also for developers who implement the process execution processes. (Bizagi, 2014), also defines Business Process Modelling Notation as a graphical notation that describes the logic of steps in a business process. According to the definition, it is a notation that is specially predesigned in the coordinating of sequential processes and messages that flows between participants of different activities. Furthermore, the reason why it is important to model with BMPN was outlined by (Bizagi, 2014) which apparently are:

- BPMN is an internationally recognizable standard whose processes are widely accepted.
- BPMN is independent of any process modelling methodology.
- BPMN creates a standardized bridge which reduces the gap between business processes and their implementation.
- BPMN enables you to model in a unified and standardized way so that everyone in an organization can understand each other.

2.2 Building Information Modelling (BIM) Application

BIM are proven to be valuable in the lifecycle of buildings. It has shown the ease of communication exchange between all stakeholders of the buildings lifecycle which includes Architects designs, the construction engineers and ultimately, the facility managers who themselves are responsible in the operation and maintenance of the delivered product through the use of IFC exchange format. IFC covers a wide range of information valuable for HVAC related problems and such information includes the following such as **IfcObjectPlacement**, **IfcRelContainedInSpatialStructure**, **IfcSpatialZones**, **IfcRelFlowControlElement** and so on, (Xue, 2015). The following is an example of an **AHU Ifc Schema** from (Liebich, 2009):

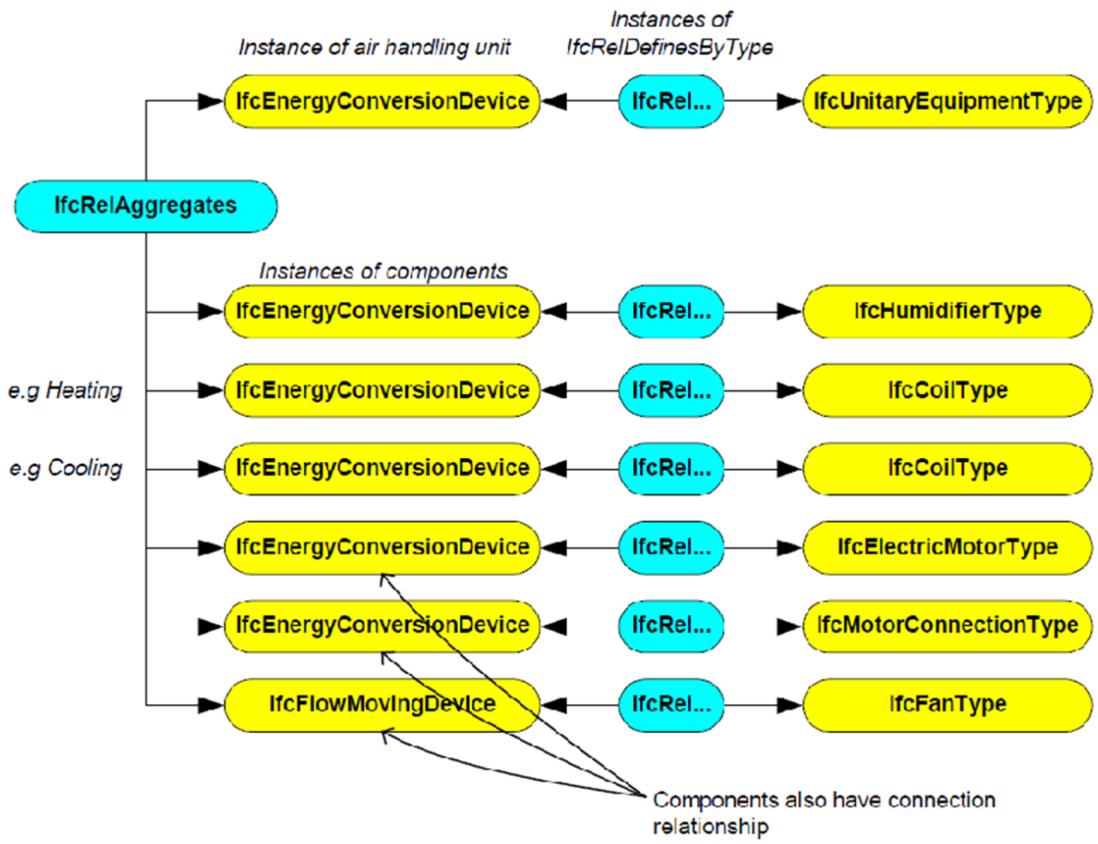

Figure 2: Aggregation of Components in AHU (Lieblich, 2009)

In this research, the BIM method will be used to ascertain the problem spaces or location and also tracing it to the précised cause of the problem. By this, it simply involves the representation of IFC instances and classes shown as nodes and the corresponding relationship between these nodes will be connected by arrows which therefore indicate the flow of air movement. Additionally, these nodes and arrows would be differentiated into central and terminal systems respectively. Graphical representation of the 3D geometry is as follows:

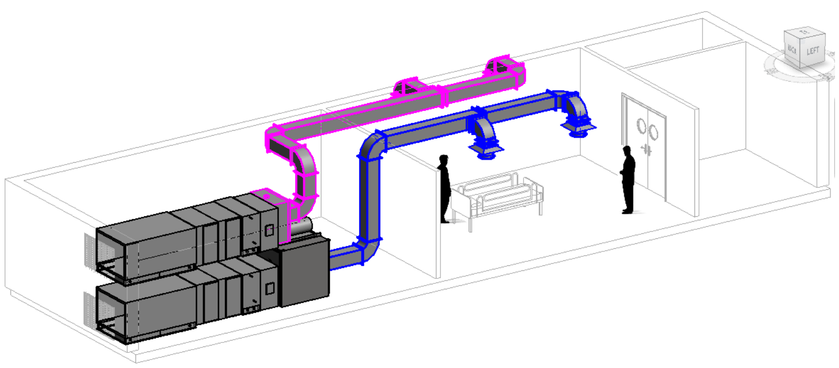

Figure 3: Graphical Representation of HVAC 3D Geometry

2.3 Failure Mode and Effects Analysis (FMEA) Application

The FMEA is actually used for detecting possible failures that might occur within equipment of components. The overall procedure for establishing an FMEA firstly begins with the drawing up of the analysis definition which is related to the scope of the analysis, after which a functional block diagram is used also to set up the graphical boundaries of the system in question and then setting up the FMEA Table with major information such as identifying failure modes, performing analysis of effects/causes of failures, failure detection, likelihood of failures and of course corrective actions proffered. Actually, the main aim in this part is to further look at the possible threats that are attributed to the problems that were firstly highlighted in the BIM section above. After which, other related and possible root causes can be listed in as well in the FMEA table.

2.4 Business Process Modelling Notation (BPMN) Application

The next method in this research is the use of the Business Process Model to reflect how the problem would be solved or addressed and which exact processes it will follow to actualize the maintenance of the HVAC mechanical problem. (Lucas, 2012), stated that process models are used to document, analyse and redesign workflows and look at information exchange and communication and methods of integrating technology to improve workflow design. He further noted that BPMN is a graphical method for depicting the sequences of processes within the process model and this would definitely be used in this research extensively. This is a process that has to do with several tasks occurring in logical sequence to achieve a common goal within different processes or domains. The essence of the BPMN as a method applied in this research is to enable a better understanding of which required information could be derived from the activities captured in each key players of the process. The key players range from clinical staffs and healthcare management to facility management and operations staffs alike.

2.5 UML Use-Case Scenario Application

The use case diagrams itself, does not contain the integral information adequate to describe what every feature of a system does. Therefore, due to this reason, the Use Case diagram has to be complemented by with a scenario. Then by definition, a Use Case scenario simply explains the interaction between the user and the system. A scenario is a sequence of actions that illustrates behaviour (Williams , 2004). The writer further claims that a scenario may be used to illustrate an interaction or the execution of use case instances. Scenarios are used in a scenario-based requirements elicitation, a technique of asking questions related to a descriptive story in order to ascertain the design requirements (Williams , 2004). Therefore, the use case implemented in this research is primarily to collate all necessary information requirements that could be used to support facility management operations in healthcare centres. These use cases would be formed on the basis of these use case requirements that includes preconditions, basic/main flow of event, sub flow of event and finally the alternative flow of events. Following the use case requirement is the graphical representation of each use case scenarios designed in Eclipse Integrated development environment (IDE) version 2.0. This application is normally used in the Information Technology industry as a first phase to designing a full-fledged application for users. Similarly in this research, the UML use case diagrams would be used to reflect the activities that have been carried out in the BPMN sections and the resultant will be the crucial information requirements meant to support HVAC maintenance in healthcare centres.

Conclusively, this chapter seem to go through all modelling methods that could be used by facility managers to address facility related problems, especially in healthcare centres. Having followed the logical walk-through, the highlighted problems of inadequate information communication and exchange between healthcare workers and facility management personnel will be addressed in this research by using a case study of an operating room temperature problem to show how the above explained methods could be applied. This applied methods would reach a self-supporting information requirement to assist facility managers combat facility problem and any other potential issue in the future.

Chapter Three

3. Literature Review

3.1 Healthcare HVAC Guideline and regulations

As earlier said, ventilation is quite used in all kinds of healthcare environments to provide a safe and convenient surrounding for both patients and staffs. Hence, statutory requirements are involved in the healthcare sector to reduce the risk placed on stakeholders and this has been established in the form of a correlation between air-borne infections and indoor air-quality. Following this reason, (Department of Health UK, 2007), have drawn up a list of statutory requirements that should be adhered to and which would be addressed later here. The department of health has engineering health technical memoranda which give comprehensive advice and design for the installation and operation of specialized buildings and with such engineering fabrics for the use of optimum healthcare delivery. Therefore, the following guidelines for HVAC systems are embedded in the important requirements reflected below.

Ventilation Minimum requirement (UK Standard)

General requirements

- All ventilation systems should be inspected annually to ensure conformity with minimum requirements which are designed to

  (a) Ensure safe access when carrying out routine services and maintenance activities.

  (b) Prevent and control risk associated with *Legionella* and other hazardous organisms.

  (c) Check that the system is fit for purpose.

  Every effort should be made to ensure that all air handling units achieve the minimum requirement that is set out.

Annual Inspection and Ventilation requirement

Ventilation Systems Inspection

- All ventilation systems should be subjected to at least an annual simple visual inspection.
- The purpose of the inspection is to establish that:
  (a) The system is still required
  (b) The AHU conforms to the minimum standard
  (C) The fire containment has not been breached
  (d) The general condition of the system is adequate for purpose
  (e) The system in general is operating in a satisfactory manner.

  It is also recommended that a simple checklist is used to record the results from the inspection.

Inspection & Maintenance

General

- Inspection and maintenance activities should be assessed to ensure that they do not create hazards for those who undertake the work or for those who could be affected by it.
- The degree and frequency of the maintenance should be related to the function of the systems, its location, its general condition and the **consequence of failure**.
- Specimen inspection and maintenance checklist are given in the appendices.

The above ventilation requirements are typical UK standard stipulating general requirements, ventilation system inspection and inspection maintenance which informs the way healthcare HVAC maintenance should be carried out in order to prevent issues like the one we will be examining in this research work.

3.2 Integrating HVAC Maintenance Standards to information Management

In order to satisfactorily support the obvious response to facility events, aspects of the Heating, Ventilation and Air-Conditioning (HVAC) maintenance standards needs to be fused into the framework of information management to solidify the requirements needed for different types of problems or situation. Areas in the code of standard in ASHRAE 170 – 2008 stipulates that: Alterations to mechanical systems serving the buildings heating, cooling or ventilation needs shall comply with the requirements of “systems and equipment” applicable to those specific portions of the buildings and its systems being altered (ANSI/ASHRAE/ASHE Standard 170-2008, 2008). It further says, any alteration by the installing of a new mechanical equipment or component must be in conjunction with the alteration as a direct replacement of existing mechanical equipment shall comply with the provisions in the appropriate sections. AHUs are invaluable in healthcare environment and it provides not only convenient environment but also vested with the responsibility of getting rid of contaminants in the air, provide conditioned air and likewise mitigating the easy transmission of nosocomial air infections by virtue of a functioning ventilation system. Going forward, aspects of the standard regulation guidelines shall be highlighted as it relates to the situation of the research case study which of course would be reflected below in the table.

Table 2: Sections of ASHRAE Standard Integrated to the information Framework

Regulation (ANSI/ ASHRAE/ ASHE Standard 170 - 2008)	**Information**
Sectional Provisions (6.1, 6.1.1)	Ventilation Upon Loss of Electrical Power Outage.
Sectional Provision (7.4, 7.4.1, a & b)	Surgery Rooms, Class B and C Operating rooms.
Information Annex A (A2, A2.1, A2.3)	Special maintenance for HVAC Units, Fan - Coil units and heat pumps, Fan – Powered Terminal units.

In this research, the above HVAC maintenance standard integration with information management simply examines aspects of the *Ashrea* standard that gives more details of the important sections that informs this research work.

3.3 BIM in Healthcare Facility Management

The integration between facility management activities such as maintenance and operations and healthcare information technologies are crucial to the delivery of quality services in respect to patient safety within the hospitals physical environment. “One critical and important way that evidenced-based design improves safety is by reducing risks from the hospital-acquired infections” (Ulrich, Xiaobo, Zimring, Anjali, & Choudhary, 2004). In this regards, the researchers simply argued that the design of a hospitals physical environment goes a long way in affecting how air-borne infections could be transmitted through the air and contacts in certain routes within the care-giving environment. Additionally, it is quite evident that many studies have reflected how important indoor air quality (IAQ) within the healthcare environment and the HVAC play enormous role in mitigating against the increase of air pathogens thereby impacting on infection rate possibility. Furthermore, several studies have shown that sources of pathogens that lead to high air-borne infection rates (especially in operating suites) are generated from areas such as in the type of filters, direction of air flow and pressure, air changes per hour n rooms, humidity and ventilation systems cleaning and maintenance (Ulrich, Xiaobo, Zimring, Anjali, & Choudhary, 2004). The researchers equally argued that there has been convincing evidence that immune-compromised and other high-acuity patient groups have fewer incidences of infections when within the HEPA-filtered isolated rooms.

The application of BIM has been in the design and construction phase of buildings and lots still have to be done in the operations and maintenance phase of buildings. In fact, a great deal of research have been conducted to inform this very subject which includes the extension of BIM into construction process by documenting 3D As-Built, produce a 4D- Constructed model and capture plus storing construction documents for the owner during the subsequent phases in the buildings lifecycle (Goedert & Meadati, 2008). Creating as-built documents from 2D documents to support facility geometric information (Lucas, 2012). Accordingly, he claimed that facility managers who work within the hospital surroundings are usually in charge of running the operations and maintenance of the integral healthcare infrastructure which for the most part, are complex in nature, and clinical staffs rely on to carry out their ethical duties. The responsibility to carry out this optimum operations and maintenance entails a great deal of organized information system. Due to the fact that healthcare facilities are quite complex in nature, and as a result of their rendered services, the information generated from these type of buildings are usually enormous because the information are obtained from the lifecycle of these particular kind of buildings. By means of lifecycle includes the design or conceptual phase, the construction phase, operation and maintenance and all through to the disposition of these properties. Therefore, facility management staffs should be able to manage this information adequately in order to enable them support the primary purpose of the building during the operation and maintenance phase of its lifecycle. The lapses like the mismanagement of facility management issues could be bridged by exploring the use of BIM and ontology development within the healthcare environment. The main purpose of integrating the ontology in BIM within a healthcare surrounding is to enable the collection of needed information to facilitate facility management issues promptly. Additionally, BIM for the owner can yield countless benefits for instance, according to (May & Geoff, 2017) they stated that “BIM can bridge the information loss associated with handling a project from design teams, to construction teams and then to building owners or operators by allowing each group to add to and reference back to all information they acquired during their period of contribution to the BIM model”.

3.4 FMEA Application in HVAC Maintenance

According to Scott (Mackler, 2012), he highlighted series of objectives for performing failure mode and effects analysis including the following:

- To ensure that potential failure modes and their effects are identified and ranked as to severity, occurrence and detection.
- Provide assessments as to risk ranking based on RPN (Risk Priority Number) and generate action register to burn down risk – hence slashing lifecycle costs, improving reliability and durability of systems.
- Prioritize the engineering efforts and resources based on the assessment of potential failure impacts to the products and eliminate or minimize the impacts of potential failures to the product.
- Provide the information for development of an efficient and effective preventive maintenance plan.
- Establish closer links between production, quality, facilities engineering and maintenance.

With wealth of FMEA experiences carried out for several aspects in industries like aerospace assembly to HVAC systems and cleaning equipment, (Mackler, 2012) also stated, that most cases or issues were not limited to predictive or preventive maintenance which were, carried out by corrective action plans but in some cases serious life threatening and safety issues were brought to light and adequately dealt with before a disaster could occur that might lead to fatality.

The main objective of an FMEA is to evaluate all parts of a system or process. Also, FMEA results are critical to ensure that system reliability and safety objectives are met, as well as Corrective actions to improve the analysis (Sequera, 2011).

Furthermore, there seem to be three main types of FMEA as argued by (SAE International, 2009) and rightly supported by (Sequera, 2011) which are Design FMEA, Machinery FMEA and Process FMEA. Giving further elaborations, the Design failure mode and effects analysis deals more with initial designing for manufacturing products or assemblies, certain functional requirements and prospective alternatives. In actual fact, the Design FMEA should be wrapped up early enough and accurately and appropriately before the commencement of producing the tools for market consumption. Meanwhile, the Manufacturing FMEA supports the design processes by the reduction of failures through numerous areas like aiding in the evaluation of the so-called equipment function, its requirements and obvious alternatives. Also, increasing the probability of potential failure modes and effects on the machinery, that has been extensively taken into consideration during the design and development phases etc. Lastly, the Process FMEA is usually carried out to satisfy the following such as identifying process functions and requirements, identification of potential products and process related failures, assessing of the potential customer effects, to mention but a few. The latter is more related to this research as it explains how HVAC systems are required to complete the healing process in healthcare operating rooms. Getting rid of indoor air contaminants, odour and noise from such special areas is a great deal of function carried out by the HVAC system and the Air Handling unit components are likewise very expedient in this regards.

3.5 BPMN Application in Facility Management

The use of BPMN in this research is to obtain the necessary information needed to further build the information architecture to resolve such HVAC malfunctioning issues in healthcare centre. However, the core meaning and areas of the Business Process Modelling Notation has to be fully elaborated for a better understanding of how facility managers could make good use of its potentials. According to (White, 2004), says that BPMN defines a Business Process Diagram (BPD); which is based on a flowcharting technique tailored for creating graphical models of business process operations. A Business Process Model, then, is a network of graphical objects, which are activities (work or task) and the flow control that defines their level of performance. He further claimed that the main objective for using Business Process Modelling Notation was to provide a notation that is readily understandable by all business users, right from the business analyst who create the business drafts of the processes, to the technical developers responsible for implementing the technology that will perform those processes, and finally to the business people who will manage and monitor those processes. (Bizagi, 2014), defined Business Process Modelling Notation as a graphical notation that describes the logic of steps in a business process which is designed specially to coordinate the sequence of processes and message that flows between participants in different activities. In addition to this, the main purpose of setting up a BPMN is to stress the fact that it creates a straight-forward structure for establishing business process models, meanwhile being able to face the complication inherent to business processes. To successfully handle the complicatedness of any business process using the BPMN, an understanding of the most important basic categories have to be established and this, according to White (2004) were as follows:

I. Flow Objects
II. Connecting Objects
III. Swim lanes and,
IV. Artifacts

The flow objects consist of three (3) main objects common to the BPMN which of course are EVENTS, ACTIVITY and GATEWAY. The connecting objects that are common to the BPMN are SEQUENCE FLOW, MESSAGE FLOW and ASSOCIATION. The Swim lanes are made up of the POOL and LANES. And lastly, the artefact consists of DATA OBJECTS, GROUP and ANNOTATION. (White, 2004), further elaborated these crucial aspects with concise diagram to show and these are

Events: This occurs during the course of a defined business process. Circles depicts the nature of an event and there are three types representing the start event, intermediate and end events

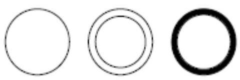

Figure 4: An Event (Source: Introduction to BPMN by Stephen White)

Activity: Here, the activity represents a term meant for work or a job that has to be performed in the chain of the business. This also comes in main task and sub-task or sub-process which is the same however, the sub-process has a plus sign in the middle of the icon to show that there are embedded activities within an activity. It is usually represented in a rounded rectangle as shown as:

Sub Process

Figure 5: An Activity (Source: Introduction to BPMN by Stephen White)

Gateway: this is basically applied when there is a need of diverging and branching off from a particular activity and likewise the convergence or meeting at a particular activity. This looks like a diamond kind of shape and its internal markers simply tells how its behaviour would be due to its control.

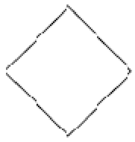

Figure 6: A Gateway (Source: Introduction to BPMN by Stephen White)

Meanwhile, the connecting objects that perform certain function would be elaborated as follows: Sequence Flow: this is simply used to indicate the order of which activities would be carried out in a defined business process. This is usually represented in a solid line with an arrow head at the end of it.

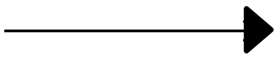

Figure 7: A Sequence Flow (Source: Introduction to BPMN by Stephen White)

Message Flow: This is usually shown for messages between two participants with different processes who send and receive this connecting object in form of messages. Mostly two pools are where the message flows are used and it is represented with dotted line and an open arrow head.

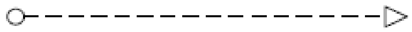

Figure 8: A Message Flow (Source: Introduction to BPMN by Stephen White)

Association: This is used to associate data, text and other artefacts whilst indicating the inputs and also outputs of any activity.

Figure 9: Association (Source: Introduction to BPMN by Stephen White)

Swim lanes in this regards are also used to indicate the separate activities that goes on within any category. This actually houses the integral activities in a BPMN and they are divided into pools and lanes. The pool simply creates the environment where separate lanes or designated parties or department interacts with each other. In otherwords, the lanes show the partition that does exist between different departments within the pool that houses these several lanes. A typical example from (White, 2004), is shown below.

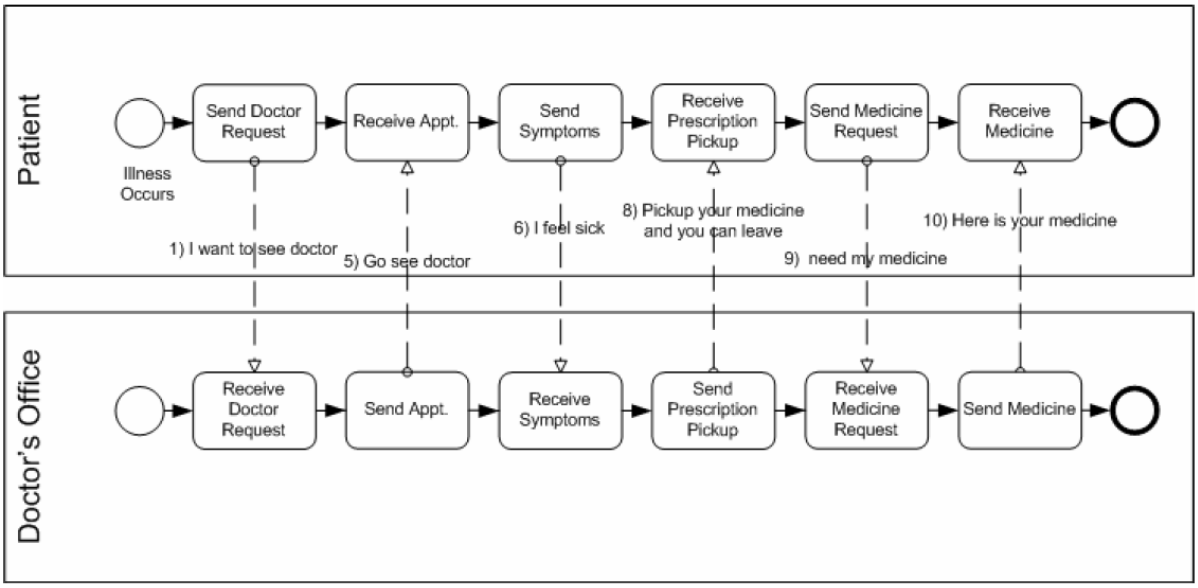

Figure10: Example of a BPD with Pools (Source: Introduction to BPMN by Stephen White)

Then the artefacts explain the following:

Data Objects: this is very critical in this research as it reflects which information or data is required from the activities. Besides, they are normally connected to several activities through associations and are usually depicted with a file type icon.

Figure 11: A Data Object (Source: Introduction to BPMN by Stephen White)

Group: These are normally used just for documentation purposes and it does not affect the sequence flow at all.

Figure 12: A Group (Source: Introduction to BPMN by Stephen White)

Annotations: This is simply an additional text area that is provided to explain more details about any task or activity to a BPMN reader or user.

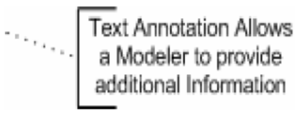

Figure 13: Annotation (Source: Introduction to BPMN by Stephen White)

Similarly, (Lucas, 2012) described in his work, on how facility management activities would reflect in a Business Process Modelling Notation (BPMN) diagram. Firstly, a complete case scenario was obtained from a practical case-study involving a cooling line serving the air-conditioners within the in-patient care building got broken and thereby causing it to go offline. This actually led to an increase in the internal temperature due to the intense heat of the outer temperature because it was during a mid-summer season. An appropriate response was well documented in the form of a BPMN Diagram to reflect possible reactions of parties that were involved to the case and how it was handled. Most importantly, the researcher made enormous strides by highlighting areas that were crucial to information needs and requirement for futuristic work-flow for healthcare facility management.

3.6 Unified Modelling Language Analysis

The importance of tasks such as analysis and design cannot be over-emphasized especially during the development of any software system. According to (Richters, 2001), who added that there are numbers of divers methods and languages that supports systematic approaches to the tasks of constructing software systems in which the *Unified Modelling Language* (***UML***) has gained considerable recognition in this regards. Now according to (Object Management Group, 1999), an acronym for Object Management Group emphatically defined *UML* as a language for specifying, visualizing, constructing, and documenting the artefacts of software systems, as well as for business modelling and other non-software systems. They further claimed that the *UML* represents a collection of the best engineering practices that has proven successful in the modelling of large and complex systems. Therefore, as the name goes Unified Modelling Language is simply a group of modelling notation standardization and unification of Booch, Rumbaugh, Jacobson, Mellor, Shlaer, Coad and Wirf-Bloch. These modelling notations from these several authors where brought together as one by the Object Management Group (OMG) in 1995 to form a unified Modelling Language that cuts across all domains due to its standardization and acceptance. That is to say, the UML came about when during the fusion of divers techniques from three notable object oriented designers such as the prominently object oriented analysis design (OOAD) from Grady Booch, Object Modelling techniques (OMT) from James Rumbaugh and last from Ivar Jacobson who is the author of Object Oriented Software Engineering (OOSE): they decided to come together in one alliance to form a unified object oriented analysis design known as a Unified Modelling Language with common semantic models alongside syntactic notations and diagrams which was approved generally by the Object Management Group.

In addition to the above definition given by the Object Management Group about the *UML,* they equally went further in describing the primary design goal that every UML ought to achieve which includes the following:

I. Provide users with a ready-to-use, expressive visual modelling language to develop and exchange meaningful models.

II. Furnish extensibility and specialization mechanisms to extend the core concepts.
III. Support specializations that are independent of particular programming languages and development processes.
IV. Provide a formal basis for understanding the modelling language.
V. Encourage the growth of object tools market.
VI. Support higher-level development concepts such as components, collaborations, frameworks and patterns.
VII. Integrate best practices. (Object Management Group, 1999).

It can be known here that every UML model conforms to the OMG standards if it respects all requirements specified in the standard documents like the goals stated above. In this research, one of the OMGs desired UML goals listed above, as applied here would be goal number one. That is to say, the goal of constructing the UML analysis in this research is to primarily provide users such as facility management personnel or staffs with a read-to-use expressional visual modelling language not only to develop models but also to exchange meaningful models that might reflect in form of GRAPHIC USER INTERFACE (GUI) in its outright implementation. Furthermore, there are three main building blocks of a unified modelling language (UML), according to (TutorialPoint, 2017), which are **Things**, **Relationship** and **Diagrams**. There are of course 4 main types of **Things** which include structural, behavioural, grouping and annotation things. The structural things are simply the class, interfaces, collaboration, use case, components and nodes. These main reflects the static elements in the construction of a model. As for the behavioural, this simply explains the verb part of the *UML* as it shows how it changes over a period of time. when Grouping things involves the organizational part of the UML for instance the packaging part. In a situation where an explanation involves in the total description of elements in the form of comments in the UML model, then it is seen as Annotational things.

Another category of the building blocks of every UML is the **relationship** category. Here, it simply looks at the connections and links between the things that were listed above and there are four main types of relationships namely dependency, association, generalization and realization. Dependency relationship is simply a semantic link between two things such that a change in one thing would bring a change in the other thing. Hence, a change in the independent thing would definitely bring a change to the dependent thing. The association explains the structural relationship of group of links with similar structure and behaviour. Generalization represents a further relationship between sub-classes and super-classes such that there is a form of inheritance of common structure and behaviours.

The last part of the UML building block is the Diagram category. (TutorialPoint, 2017), defines diagrams as ‘graphical representation of a system’. It comprises of groups of element which are nine in numbers (9) and displays only by diagrams that includes: class diagram, sequence diagram, use case diagram, object diagram, activity diagram, collaboration diagram, state chart diagram, component diagram and deployment diagram. According to (Williams , 2004), who stated that these groups consisting of nine (9) diagrams are therefore narrowed down towards five (5) main diagrams namely class diagrams, object diagrams, use-case diagrams, sequence diagrams and activity diagrams known as the fundamentals of UML. For this research, the use-case diagram would be applied to the analysis of the FMEA, BIM and BPMN. Asides the building blocks of the UML, there is a need for semantic consistency with regards to the rules that guides the relations of other models within the system and these rules includes the following as stated by (TutorialPoint, 2017), to be **Names**, **Scope**, **Visibility**, **Integrity** and **Execution**.

3.6.1 Basic UML Notation

The basic UML notations of the building blocks include the following such as class, object, components, interface, package and relationships. The class itself has three (3) main areas which represent the upper layer, the middle layer and the bottom layer. The first layer is where the name of the class is being held while the middle layer has to do with the attributes of the class and then the bottom part simply represents the operations done by the class. An example of a class is shown below.

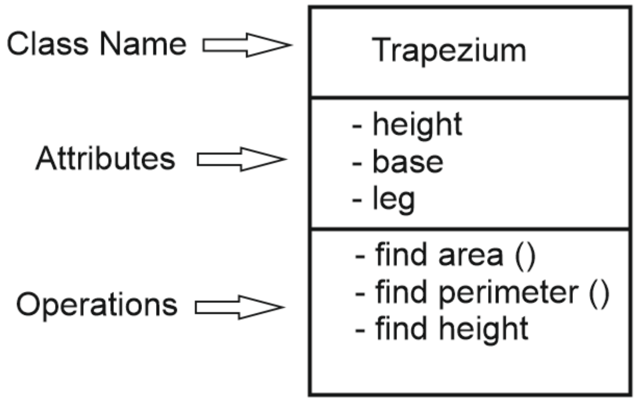

Figure 14: Class Diagram sample (Source: TutorialPoint)

The “Object” is another UML notation language and it is very important to discuss here because it would be used in this research. That is to say, the object name can be the name of the original class or package name in which it represents the instance of. It is just a rectangle divided into two parts which contains the class name or object name plus the attribute part containing the values of that instance. A typical sample is shown in the figure 2 below.

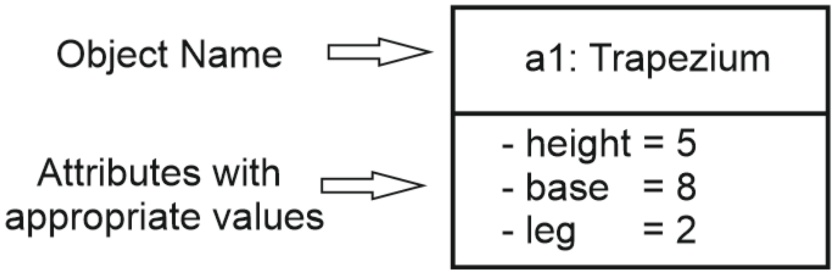

Figure 15: Object Notation Diagram (Source: TutorialPoint)

A component, as described by the (Object Management Group, 1999), is a graph that is connected by dependency relationships which may also be connected to components by physical containment representing composition relationship. That is to say, it is a physical and interchangeable area of the system that conforms to and provides the realization of a set of interfaces. The OMG shows an example of what components looks like which is shown below.

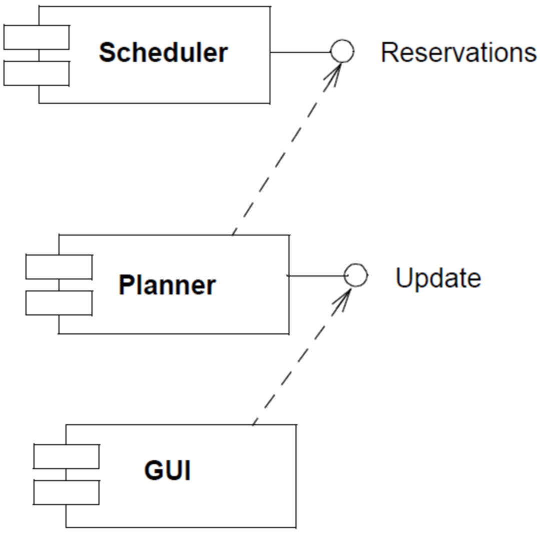

Figure 16: Component Notation Diagram (source: OMG, 1999)

The main relationship notations include the following different types which were dependency, association, direct association, inheritance, realization and aggregation. These relationships really play a great deal between related elements in the context of the UML application.

3.6.2 Use-Case Diagrams

As simply put, a Use-case Diagram displays the connection or relationship among actors and the use cases within a system, (Object Management Group, 1999). That is, it reflects the links between actors and the activities within a system also known as use cases. Similarly, the (TutorialPoint, 2017), also defined a Use-case diagram as a "description of sequence of actions a system performs yielding visible results. It shows the interaction of things outside the system with the system itself". Here, the writer explains the fact that the system is an entity on its own which does interacts with things that are external such as the actors that uses this system. According to (Williams , 2004), argues specifically that the use case diagrams are applied during requirement elicitation or extraction and analysis as a graphical means of representing the functional requirements of the system. In fact, he further claims that a use case typically represents a major piece of functionality that is complete in itself from the beginning to the end. Ivar Jacobson was the one that coined the name "use-case", and therefore defined it as "a sequence of transactions performed by a system that yields an outwardly visible measurable result of value for a particular actor". To add to the above definitions, (Object Management Group, 1999) highlighted the notational aspect of use case diagrams by explaining that it is a graph of actors, a set of use cases alongside possible interfaces or combinations and the relationships between these elements. These relationships are simply the associations between the actors and several use cases and likewise generalization between the actors involved.

Basically, a use case diagram is one of the two main types of UML models that are common known as the behavioural models that are specifically used to display functional requirements while the other type of UML model is the technical requirement and details known as the structural models. The former deals with questions such as "what the system actual does" and the latter questions "how the system does it". Therefore, a use case diagram captures the functionality of the system from the users' perspective. That means, a use case diagram is simply a collection of several use cases in which each use case is the smallest unit of functionality. It also specifies the idea that is applied for defining the functionality of an integral system. According to (Object Management Group, 1999), the use case package has its key elements known as the Use Case and the Actor. The elements in a use case are simply used to define the behavioural pattern of any system in this package.

Actor: "defines a coherent set of roles that users of an entity can play when interacting with an entity. Hence, may be considered to play a separate role with regards to each use case with which it communicates" (Object Management Group, 1999). Meanwhile, (Williams , 2004) defines an actor as whomever or whatever (person, machine or other) interacts with the system. That is to say, the actor or actors do not belong to the system entity itself because they are separate from the system. However, they constitute an entity of stakeholders that must collaborate and communicate with the system even though they have no idea about the structure of the system. Williams further stated the salient interaction patterns that must be carried out by actors which are as follows:

i) Input information to the system.
ii) Receive information from the system and
iii) Both input information to and receive information from the system.

Usually in any Unified Modelling Language, the actors are represented or shown as a "stick man". In fact, (Williams , 2004) argues that the total set of actors in a use case model is a reflection of everything that is required to exchange information with the system. It is also typical that the name of actors should also be "nouns" also not necessarily an outright particular name but only signifies the set of roles the actors carry out as regards to several use cases.

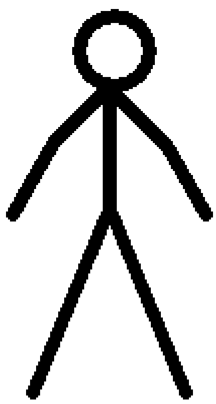

Figure 18: Sample of an Actor

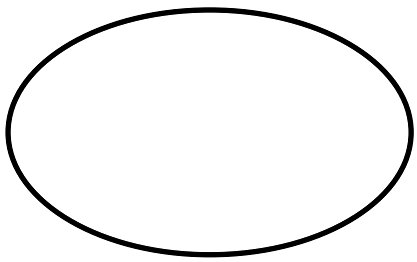

Figure 17: Sample of a Use Case (Source: TutorialPoint)

(Source: TutorialPoint)

Association symbol: this simply defines the relationship between the use case and the Actor. This is usually a plain line and it establishes the relationship between the elements here. That is to say, it specifies the additional behaviour of the use cases.

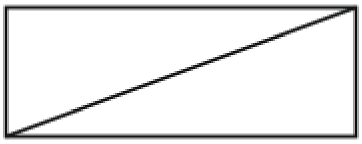

Figure 19: Association Symbol

Include: In this relationship, it is used to indicate that one use case actually depends on the other. For instance, a user needs to log in before performing further actions depending on the purpose of login in. therefore it is not possible to do anything or carryout any activity within the system without first login into the system hence, futuristic actions depends or includes login in.

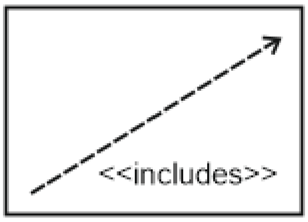

Figure 20: Include Symbol

Extends: In this type of relationship, it indicates the link between two uses in which one is optional, and the other is a more specific version of other cases. A collection of extend relationships to Use case that the use case extends.

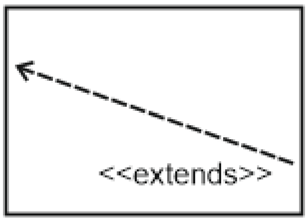

Figure 21: Extend Symbol

Generalization: This relationship is basically an indication that one element in the diagram is a more general version of other element.

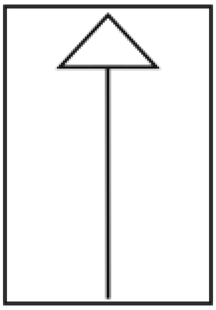

Figure 22: Generalization Symbol

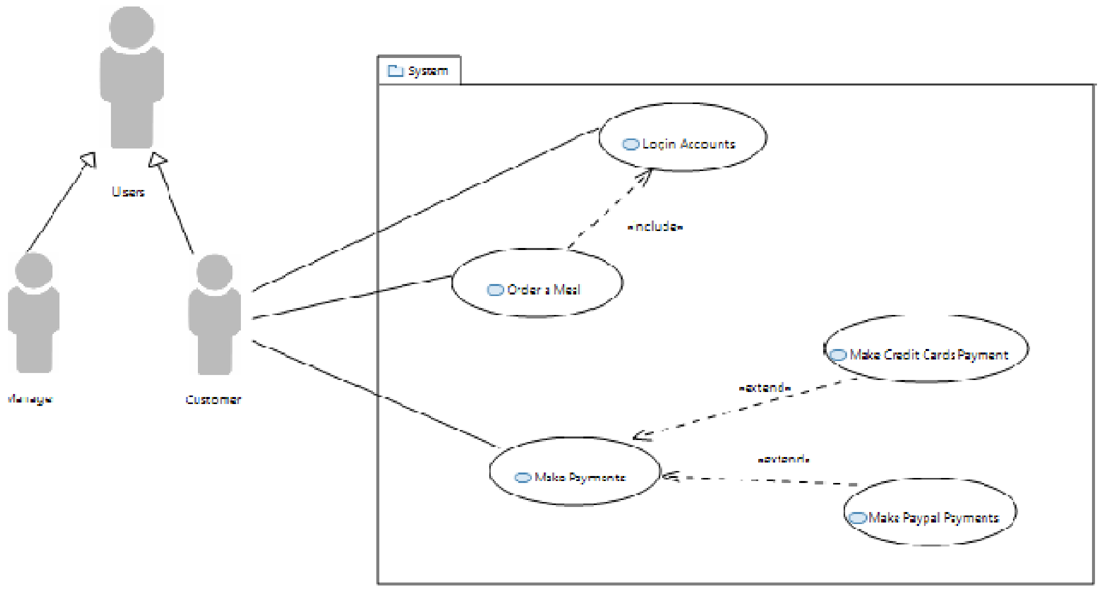

Figure 23: UML Use-Case Diagram Analysis

Chapter Four

4. Results

Case Based Method for HVAC Maintenance Information Requirements

This research will examine case analysis methods that can be used in order to develop or establish the required information that would be valuable for facility management of HVAC systems in healthcare centres in the eventuality of emergencies. Hence, pointing and elaborating divers' connections that will be created between the facility information and of course, clinical services information within this descriptive case study. In fact, this chapter seeks to show all related modelling methods that facility managers could leverage to optimize facility related activities.

Descriptive Case Study

The heating, ventilation and air conditions in healthcare centres are very crucial as it plays an important role which mainly includes the controlling of the indoor air quality especially for operating rooms. In a situation where the HVAC system serving the operating room malfunctions i.e. one or more components fails to carry out its designed purpose, this could actually pose severe health consequences to patients with deteriorating immune systems (or patients recovering from ill-health conditions) and also to clinical staffs as well. Therefore, the following descriptive case study was actually adopted from a real life case study that was examined by (Lucas, 2012). However, in this research, the case study narrative was rather modified to suit this research purposely. Hence, the following descriptive case study explains the actions taken when the supply fan in the HVAC - AHU suddenly stops working and consequently affects the indoor-air quality condition in the operating room.

Actual Narrative Case

AREA: Operating Room

ISSUE: The HVAC supply fan in the AHU serving the operating room suddenly breaks down and stopped functioning; thereby leading to a high temperature and odour within the operating room.

PLAYERS: Nursing staffs (Medical Operations), Facility Manager (Facility Management Operations), Maintenance Technician (Facility Management

Operations), Administrator (Hospital Administration), safety staff (Health, Safety & Environment), Risk manager (Facility Management Operations), Neighbouring hospitals, and security staff (Facility Management Operations).

CIRCUMSTANCE: During the mid-summer season, given the persistent highly heated temperatures of about 50 degrees centigrade external weather condition, the primary HVAC - AHU supply fan broke down and suddenly stopped working therefore no air was found entering into the operating room from the in-let HVAC terminals (variable-air-volume diffusers). Due to this situation of the HVAC system being unable to supply conditioned air into the environment, the internal temperature within the operating room suddenly becomes high to around 70 degrees centigrade just in couple of minutes as a result of the intense external heat temperature.

REACTION: The nursing staff informed the facility management operations that the operating room suite was way too hot, stuffy with slight pungency in odour. The Facility Manager fills a work-order of the required information and swiftly instructs the maintenance personnel to go straight-away to the operating room to assess the present condition of the internal environment. After a physical assessment of the area, he observed that the in-let air terminals were not supplying the room with any form of conditioned air. The mechanic decided to run a check on the mechanical system room where the AHU is located; that was where he realized that the system supplying fan had stopped functioning. The maintenance mechanic swiftly and decisively escalated the situation to the Facility Manager and then immediately turned off other functioning components within the HVAC system and also to the system serving the operating room.

Having been fully notified with regards to the updated information, the facility manager quickly dispatches the nursing manager, security officers, infections control personnel and member of the administration on ground to assess the place. Following the assessment, the nursing manager reverted back to the facility manager on the current situation being assessed. As a result of the assessment, the facility manager sends more facilities personnel to the site as stated in their standard operating procedures for emergency operation plan. In the meantime, the facilities maintenance mechanic has started fixing the troubleshooted fan supply problem. Using a scale of preference, finding the leading cause of the failure was given priority then fixing the component will be next and finally getting the HVAC system hitting the ground running again just like business as usual. To effectively fix the issue, the

HVAC system has to be turned off completely, the AHU has to be opened and the components that relates to the supply fan would be checked and troubleshooted adequately.

Furthermore, the administration personnel and nursing manager took an impromptu decision to relocate the patients in the operating room suite to alternative care sites since the duration to get the AHU running again was not ascertained. In addition to this, all critical appointments were moved to secondary facilities. It was noticed that the doctors' office and other clinicians' location had their own AHU running and functioning efficiently.

The relocation plan was addressed by the administration and apparently the nursing staffs who assisted in the movement of patients. Patients were transferred to other secondary facilities according to their level of care requirement from neighbouring hospitals. For patients that had to be transferred to this hospital with similar facilities were driven in ambulances alongside their medical records and information in order for the new hospitals to better inform themselves about the relocated patients' details. Meanwhile, for the patients whose cases, were not critical (minor cases) were discharged home during the course of this situation thereby not having to relocate them as well to other hospitals or facilities. The Facility manager oversees and ensures that the mechanic fixes the exact problem within the time-frame stipulated. Having rectified the issue, the Facility manager had to make sure that proper house-keeping was carried out accordingly. Then the facility manager ensure that the indoor air quality test is at an acceptable level resulting to the administrator approving the return of patients back to normal medical procedures.

RESULT: It took yet another twelve (12) hours to repair the faulty fan issue and the air conditioning in the internal environment took yet another twelve (12) hours to get back in line. Most importantly, as a procedural conformity, it took one extra day to re-cool the entire area to a habitable safe condition as required for healthcare settings.

Case Scenario Documentation

The actual issue was documented in form of these three following methods, firstly by Building information modelling, failure mode and effects analysis, business process modelling notation, plus finally the UML Use case scenario analysis which would be used to ascertain the information requirement that can support facility management operations. That is to say, this actually shows the way and manner facility management personnel would handle issues with regards to facility related problems occurring. Therefore, the following result is a reflection of the methods that could be used to support facility management operations especially in the areas maintenance.

4.1 Building Information Modelling (BIM) Method

The objective of this research is to show the development of important methods that could be used to support facility managers in their daily activities of providing the enabling environment for clinical staffs alongside patients to thrive positively. One of the most important methods is the application of BIM, which is used to support the facility management staffs to carry out optimum facility maintenance tasks. A lot have been said about the invaluable nature of HVAC systems in healthcare centre and this research also recognises and supports the established facts. Therefore, for the scope of this project, the actual HVAC system targeted here would be the centralized secondary HVAC system usually situated within the building while primary HVAC systems which include Chillers are situated externally but will not be covered in this project. The main aim of BIM method in this project is to show the *problem zones* of particular spaces within the healthcare centre. There is a need to describe the peculiarity of zones that possess this problem. A zone could be likened to a room/space/envelope or location within a building which could also be set of room/space/envelope or locations. According to (Xue, 2015), he stated that zones could be rooms/spaces where the air conditioning is controlled by the same thermostat which apparently is terminal systems separated for each zone. Similarly, the researcher claimed that the fundamental knowledge of components belonging to the central system or terminal system describes the type of HVAC system and the spatial scope of the reported problem.

The researcher further highlighted that the current *IfcSchema* defines *IfcSystem* to mean group of components in the same system however, does not distinguish which component belongs to the central system and/or terminal system. Therefore, in order to ascertain how BIM can assist the facility manager to locate the problematic space, an in-depth description of the HVAC system components have to be defined in the form of an *HvacGraphGenerator*. That is, a class known as HvacGraphGenerator is defined, as certain algorithm that replaces HVAC systems components to a graph-based representation (Xue, 2015). This invariably implies that each component, be it located in the central system or terminal area is represented in nodes and the arrows that connect their distribution are known as edges (Xue, 2015). The arrows simply connect two nodes together in strong relations to the flow direction of air. This relation shows the IFC connectivity between nodes by the use of *IfcDistributionPort, IfcRelConnectstoElement*, *IfcRelConnectsPort* and an *IfcFlowDirectionEnum* which reflects the air flow direction.

Furthermore, to show this connected relationship between the HVAC Components and the flow direction, this research would definitely adopt the concept of *HvacGraphGenerator* which will link all supply air ductwork connected components to any given space/rooms and vice-versa in order to create a graph-network based on connectivity approach. This *HvacGraphGenerator* composes of both the *supplyGraphMap* and the *returnGraphMap* which have *IfcSpace* Instance embedded in this IFC File. The diagrams below simply displays how BIM can help to locate zones with HVAC related problems alongside possible applicable causes of this Issue.

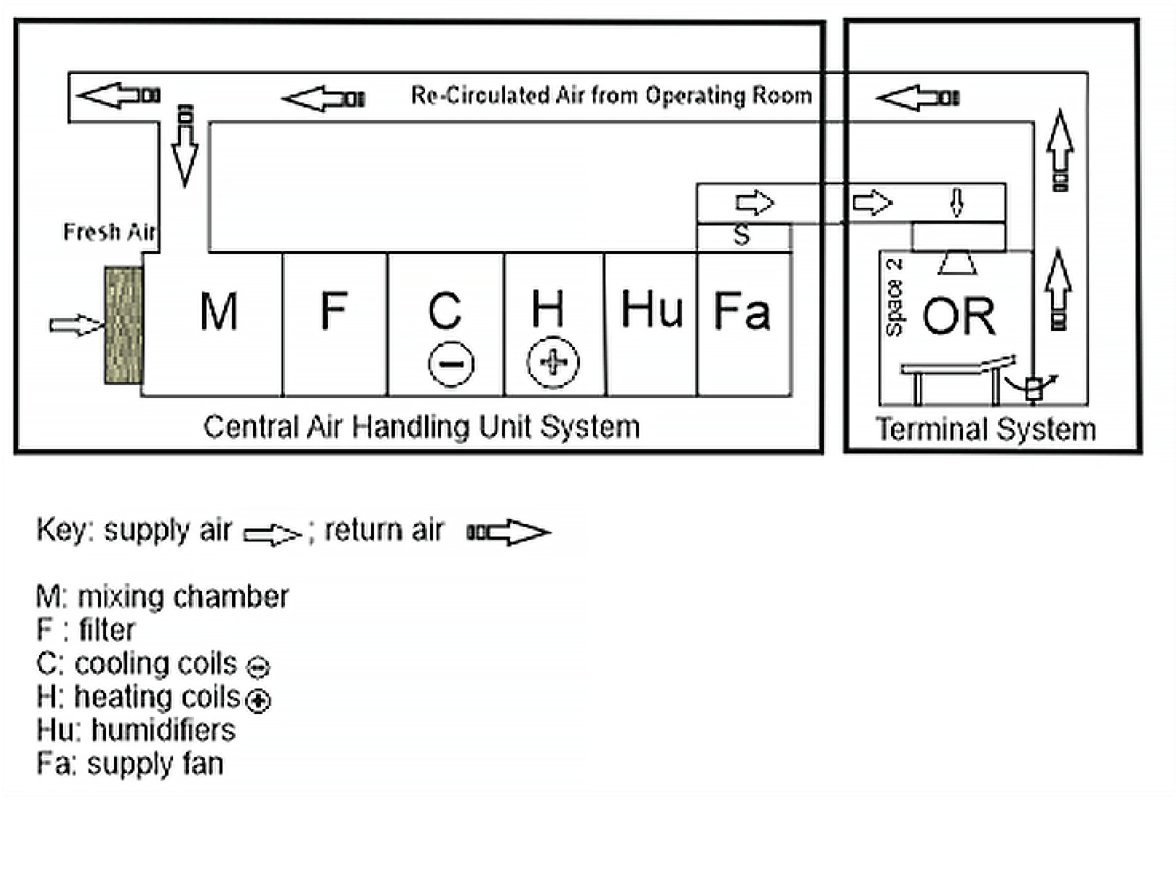

Figure 24: Schematic Diagram of AHU and Operating room

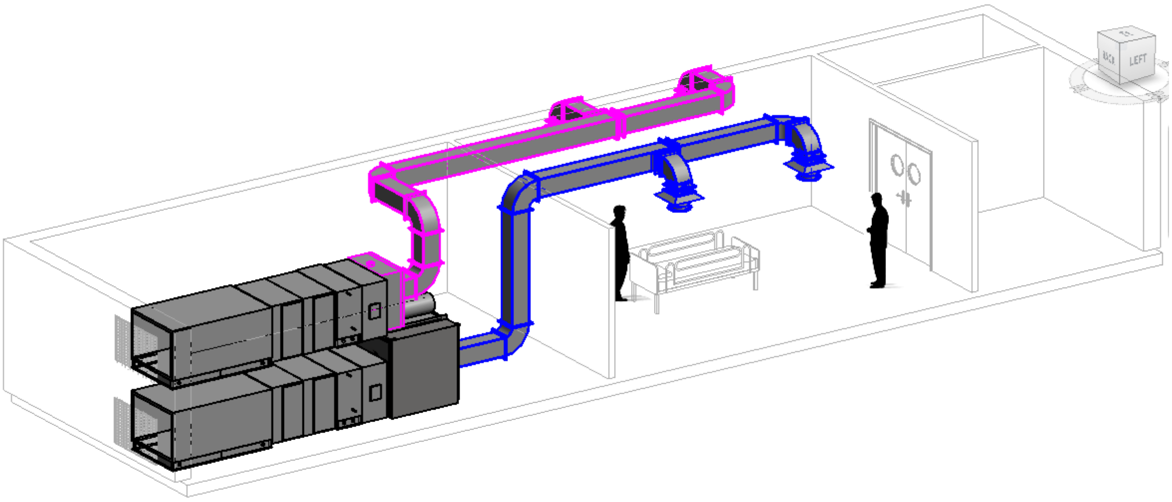

Figure 25: 3D BIM layout of the AHU and Operating rooms

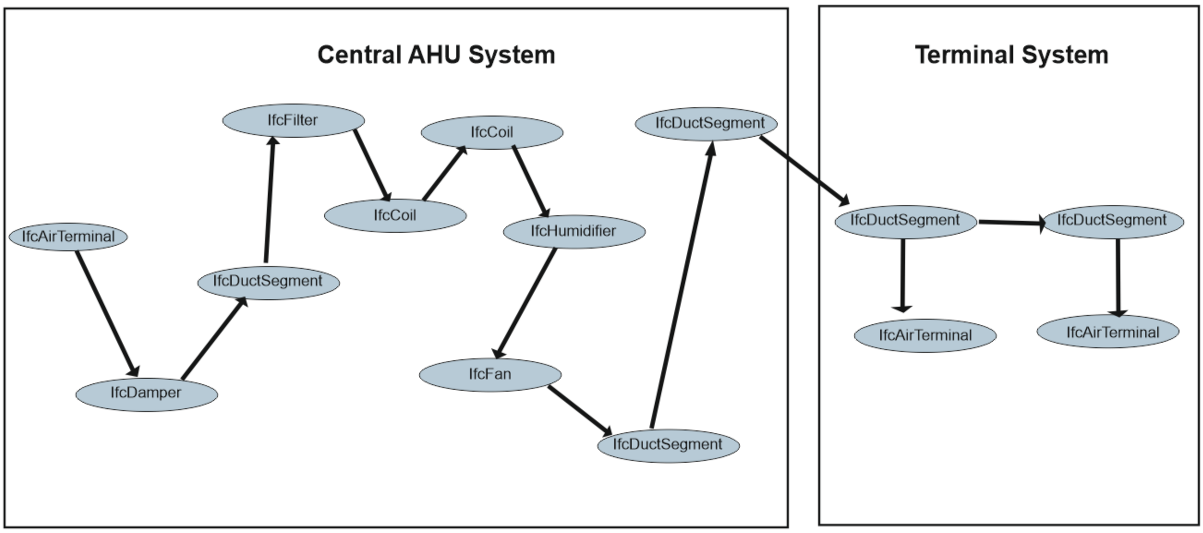

Figure 26: Graph-supported IFC Interpretation of AHU System with demarcation of Central and Terminal units

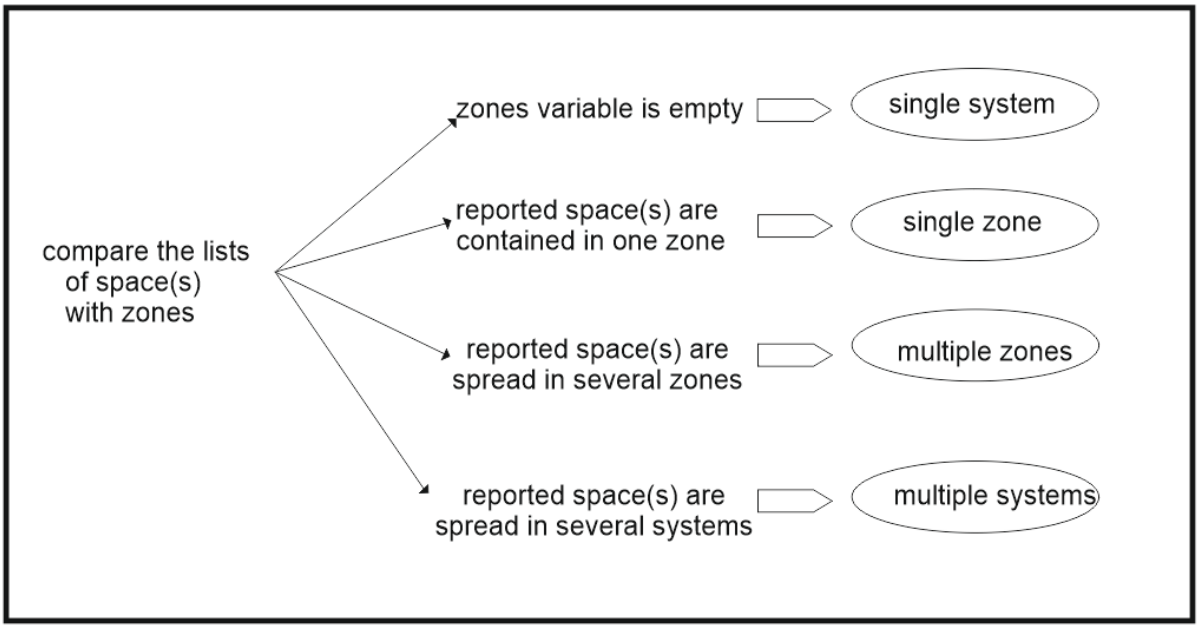

Figure 27: (a) Case-Based Reasoning Approach indicating Problem Spaces and zones.

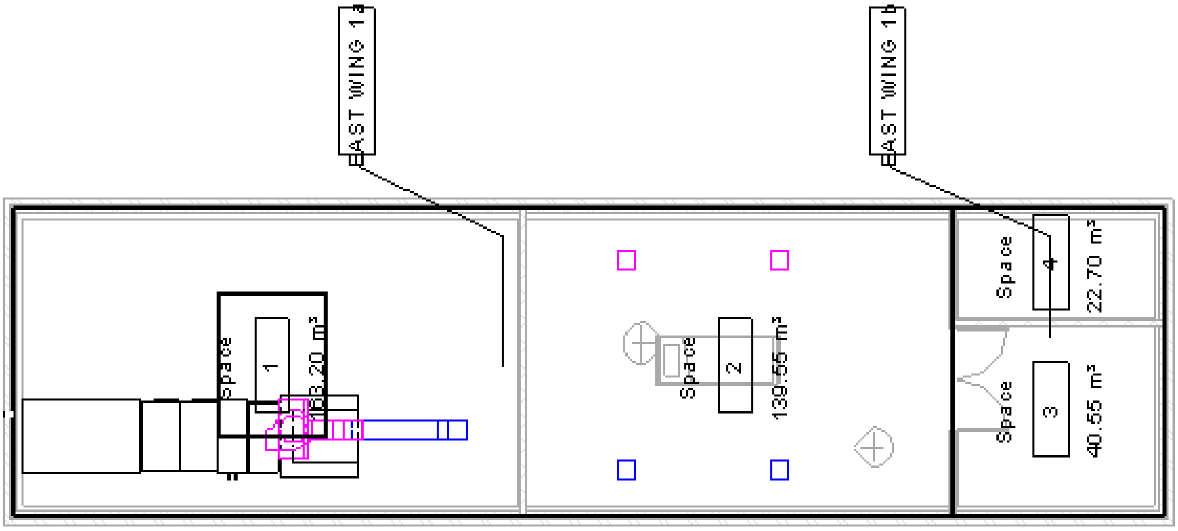

Figure 28: (b) Sample of two zones: East wing 1a and East wing 1b

Table 3: Link between Problem Spaces, Work Order Problem and Problem Location

Possible Causes of problem	Problem Type	Problem Location
Thermostat	Temperature air flow	Single Zone
Reheat Valve	Temperature, water leak,noise	Single Zone
SUPPLY FAN	Temperature, Airflow , Odour, Noise	Multiple Zones as well as Single zones
Central coolig coils	Temperature, Airflow, Humidity, Odour, Noise	Multiple Zones as well as Single Systems
Air compressor	Temperature, Airflow , Odour, Noise	Multiple Zones, Single Systems, Multiple Systems

BIM Method Analysis

From the foregoing, the above case based scenario explains how building information modelling can be of support to facility management practices in healthcare environment with the earlier diagrams showed in this research. Firstly, having received the alert from the nursing staff in form of email/phone call, there was a need for the facility manager to draw up a work order capturing very important aspects of the problem and its location. Next, to trace possible problem cause(s), a schematic diagram indicating the flow of air through the HVAC – AHU components which obviously is the central AHU system to the terminal system area that channels the conditioned air to the users (patients and medical staffs alike).

This schematic view in figure 11, is required to show which main components are in the mechanical room (HVAC - air handling unit area) as suppose to the serviced space (in this case, it is the operating room) equally known to be indicated as the terminal system region.

The BIM 3D – layout in figure 12 above, equally reflects what the schematic view represents. That is to say, it also indicates the connection between the central Air Handling Unit system region and the terminal system region of the healthcare facility. To further support the schematic view, the 3D-bim layout would rather give the facility manager a better understanding of how best to approach this issue with regards to the actual space where the problem has occurred (as indicated in the work order drafted out from the phone call the nursing staff made).

The graph in figure 13 reveals the Industry Foundation Class (IFC) interpretation of components in the central AHU system and the Terminal system as part of the healthcare facility. This graph was used as a result of the challenge of distinguishing which precise components belongs to the central AHU region and the ones belonging to the terminal system area in other to find out the problem cause. Here, it was important to make use of the concept applied by Leite and Akinci (2012); Langehelm (2013); cited in (Xue, 2015), that converted IFC interpretation of HVAC systems into a graph-based interpretation of the same HVAC systems data due to its adaptability in extracting and simplifying the topological information about the facility and overall components. In this aspect, the graph-supported *Ifc* interpretation would assist the facility management staff in creating the connectivity between the HVAC systems and the air flow direction from the air intake area to the terminal differs in the used space. Therefore, this would enable the facility manager to link the HVAC Ifc components of the supply air ductwork area as well as the return air ductwork area and labelling them respectively for better understanding of the problem cause. That is, the IFC class that holds the Ifc supply air instances and the Ifc return air instances further explains the air flow direction which indicated each component of both the Ifc supply air and Ifc return air instances interactions for a proper trouble-shooting of where the problem cause maybe with their corresponding data.

The **case-based reasoning approach** in figure 14 simply describes how facility managers can follow up the tracing of possible problems that might have caused the high in temperature and odour within the operating room. Following the earlier explanation of steps that has to be adhered to, this part is quite crucial for the facility manager to execute his judgement in a decisive manner. Therefore, in this research, the case based reasoning was also adopted from (Xue, 2015), approach that indicates that if the zones are an empty variable, then it means that the scope of the spatial problem is within a single zone/system. Then if the HVAC design is a multiple zones system, then the reported problem space (s) would be looped to check if similar zones are affected therefore, the problem spatial scope would be attributed to multiple zones otherwise, the problem is within the same zone. In this research, the HVAC system is the type that serves multiple zones however, the reported problem space is located just in one zone known as *“EASTWING 1a”* with high temperature and odour complaints from the nursing staff and registered in the work order; which makes it a single zone problem scope as highlighted in figure 14 above.

The final algorithm in the steps of using BIM to support facility management decisions is quite elaborated here in this analysis. That is to say, having obtained the reported problem space and linking it to the exact zone, there is a need to finally “connect the dots” to possible cause(s) of the reported problem. (Xue, 2015), applied a matrix method that maps the work characteristic to the applicable HVAC component space problem causes. This approach was adopted in this research by implementing the *“AND”* Logic that links the major attribute of the work order to the HVAC problem identification. According to figure 15, and relating to the problem within the scope of this research, it can be deduced that the ***supply fan*** is one of the applicable causes of a work order that is attributed to a problem type of *temperature* **AND** *single-zone as well as multiple zones*. By this, the facility manager can better avail himself with the exact cause and area to trouble-shoot when carrying out corrective maintenance by the mechanic on site.

4.2 FMEA Method

Having reviewed and completed the BIM algorithm steps to arrive at the result that shows the problem zones and possible cause(s) of the problem which was the supply fan as analysed earlier, the FMEA, would be done to create a straightforward link between the HVAC problem and the threats it poses to patients and medical staffs within the healthcare environment. With respect to each problem cause, FMEA's have the capability of checking the possibility of failures and its effects that connect to each type of failure. Earlier studies have shown that an FMEA flowchart plus a functional block diagram are the initial steps to be carried out before commencing analysis with the FMEA table. The flowchart as shown in figure 15, simply indicates how this failure mode and effects analysis in this research would be done. Firstly, the main aim of the failure mode and effects analysis will be defined which invariably is to itemize the possible components of the HVAC system that can lead to the failure of the ***supply fan*** and also look into the effects with regards to threats it poses to the patients.

Next is to develop the HVAC system functional block diagram as shown in figure 16. Here, it indicates the three (3) main areas where the research is focussed on, which are the HVAC – AHU labelled as (#*200*) series, the mechanical room as (#*300*) series and finally the Operating room labelled as (#*400*) series. Going further in this project, the actual place of interest is the HVAC – AHU which has been enlarged to scrutinize the components that makes up of the system. Moreover, the essential information that has been known so far from the BIM analysis is the problem zone and the cause of the problem. The block diagram of the HVAC system has its several components labelled accordingly however; the problem cause remains the supply fan (#270) component.

The failure modes and causes would follow suit after the functional block diagram has been drawn and relevant information retrieved. Each failure modes will be identified as this could be helpful in terms of understanding a better and possible ways to address future occurrence of similar problem type.

Therefore, the failure modes and effects analysis would be examined based on these two criteria that have been elaborated upon so far in this segment.

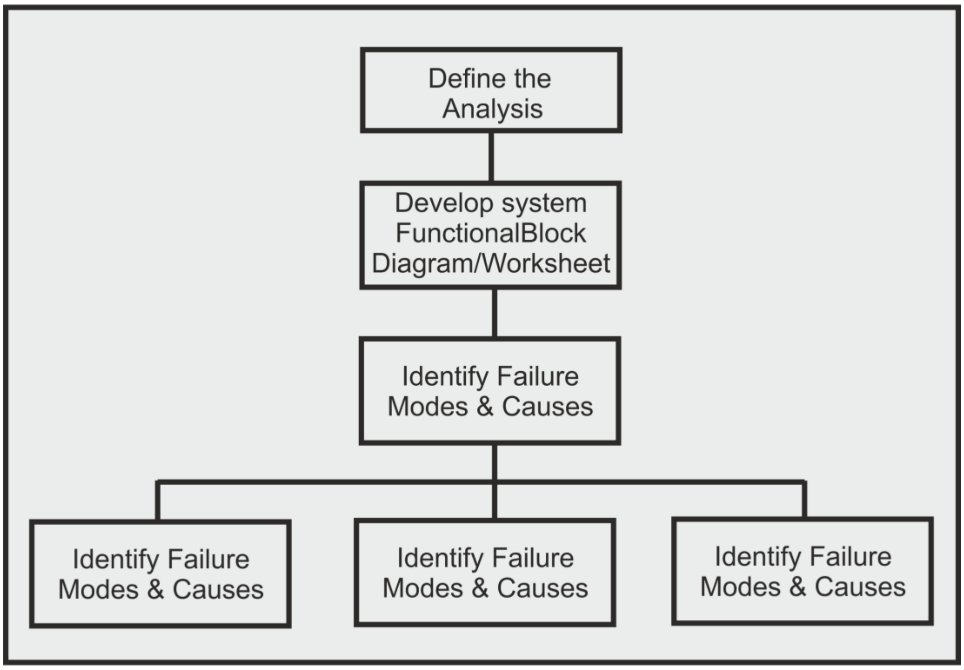

Figure 29: Example of an FMEA Flow Chart

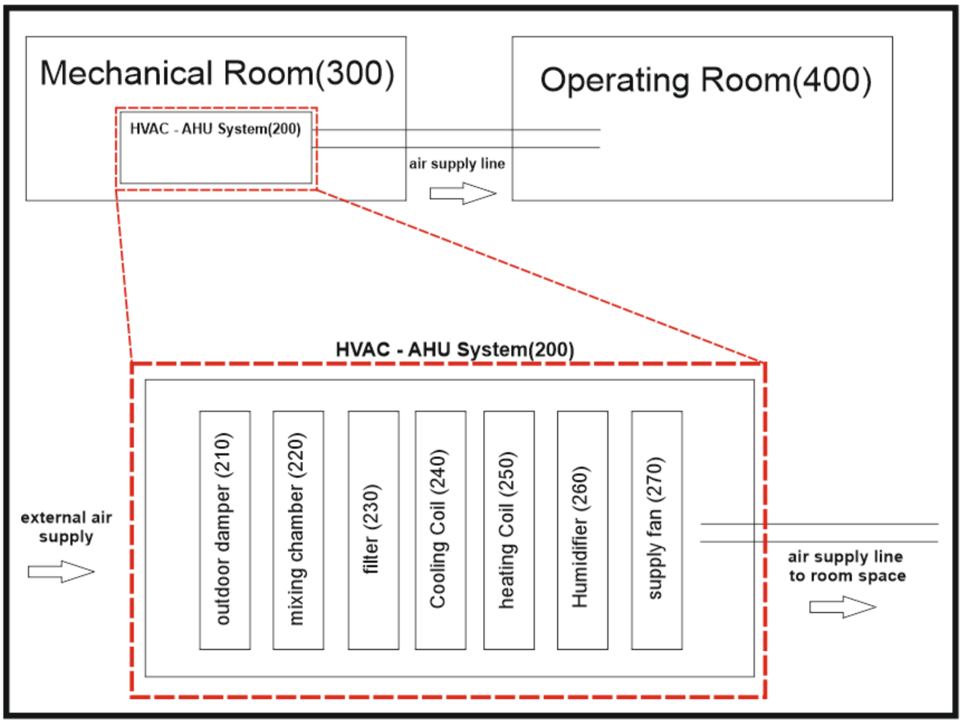

Figure 30: Functional Block Diagram of System Components

Table 4: Failure Mode and Effects Analysis of the Case Study are completely included in Appedix A below

Operational Mode:	**Descriptions:**											
Units of Description	**Description of Failure**	**Effects of Failure**	**Safeguards**	**Severity**	**Likelihood of Occurrence**	**Corrective Actions**						
ID	Function	Failure Mode	Failure Causes	Detection of Failure/ Problem	Physical Environment	Health hazard on Patients	Prevention of Failure/ Problem	Mitigation of Effects	Low/Medium/ High	Low/Medium/ High		
270.01	Air Handler Fan	Fan does not supply circulated air.	Power supply is cut-off	HVAC thermostat Sensor in the Operating room and nursing staff escalates the issue	High rise of temperature in the Operating Room(s), odour and/or stuffiness	Increase in discomfort and air-borne infection possibilities like Aspergillums which could	Frequent physical inspection of the components should be carried out.	Decongest the Operating room of some staffs and if possible relocate the patient to a similar	Medium	Medium	Turn off power source and Carry out immediate trouble-shooting of the Air handling Unit supply	

As said earlier, the items in the functional block diagram are obviously linked to the failure modes and effects analysis table above. Each component in the HVAC – AHU system is being labelled according however, with regards to the problem in this case study; several possible causes were linked to the problem. “270.01” is simply the supply fan that does not circulate the required conditioned air to the room however, the “01” digits is simply the sub-set listed from the whole fan component. The failure description parts have areas that are revealing in nature such as the failure modes, causes and the detection of the supply fan issue. The failure effects were divided into two major areas which are the effects it would have on the physically built environment and also on the users (patients and care-giving staffs) hence, were High rise of temperature in the Operating Room(s), odour and/or stuffiness and Increase in discomfort and air-borne infection possibilities like Aspergillums which could worsen patients’ health conditions due to vulnerability. Moreover, to each list of causes elaborated above in table 4 is also a corresponding safeguard approach to prevent futuristic occurrences of the problem.

Another very important area of the FMEA in table 4 was the corrective maintenance actions, this part indicates the corrective procedures that have to be done to mitigate and combat the situation. Additionally, for the purpose of this research scope, the FMEA takes into consideration just one operating room; however, this method could be applied to several rooms within the hospital. This goes to show in this project that, the failure modes and causes would support the Facility Managers to have several options for addressing the possibilities of the potential failures and threat in the course of their daily operational tasks.

4.3 **BPMN Method** – Case Study of Malfunctioned AHU supply Fan

This aspect actually reflects how the use of business process modelling notation could be used to describe the flow of events or tasks that has to be carried out by the participants involved. That is to say, it helps to show the exact role and decisions taken by each participant in the course of fixing the problem. This is actually done within the BPMN standard format. Therefore, this process model was actually completed in a documented manner to reflect each task and decision made by key players in the department and that would be elaborated below.

1) The nursing staffs experience a sudden increase in temperature plus odour due to stuffiness of the operating room and apparently escalated the issue by placing a phone call to the facility management operations following an email earlier sent.
2) The facility manager receives the phone call from the nursing staff and fills in a work order at real time.
3) The facility manager swiftly instructs the available HVAC-AHU maintenance technician to the site to evaluate the situation.
4) The AHU – technician receives the instruction and proceeds immediately to the operating room (problem space) to access and trouble-shoot the issue.
5) The technician assesses the condition and observes that the in-let air terminals do not supply conditioned air into the operating room area. The technician traces this issue to the mechanical room where the AHU is situated and realized that the supply fan was not working. He reverts back to the facility manager by placing a call as fast as possible whilst turning off the AHU system to prevent further faults to other components.
6) Having received the current information, the facility manager sends the nursing manager, safety staff and infection control staff to access the situation whilst updating the work order.
7) The first responders receive the information and proceeds to the scene for their respective assessment of the problem, potential threats and rectification approach.
8) The nursing manager reverts back to the facility manager on the assessment made so far and current response condition.
9) Following the response from the nursing manager, the facility manager sends off more management personnel with the required information about the scenario.
10) The extra personnel arrive at the scene and obtain briefings from the nursing manager with regards to the current status of the situation.
11) The AHU technician begins to solve the supply fan problem.
12) The administrator, safety officer, risk manager and security staff assessed the situation after briefing from the nursing manager.
13) The administrator and nursing manager decisively arranged to relocate the patients from the operating room to other alternative hospital due to the temperature status and time frame to fix the problem.

14) The administrator plans the relocation of in-patients and thereby coordinated the relocating process.
15) The nursing staffs engage in the relocating preparation of the in-patients
16) The administrator halts all registration of patients to that area and informs the patients.
17) The nursing staffs discharge patients ready to go home and relocate others to secondary healthcare centres.
18) The facility manager ensures the technician fixes the problem according to the stipulated time frame.
19) The facility manager ensures that proper good house-keeping is done accordingly.
20) The facility manager also ensures that the indoor air-quality test is done and meets the standard.
21) The administrator makes the approval for the returning of patients to normal medical procedures.

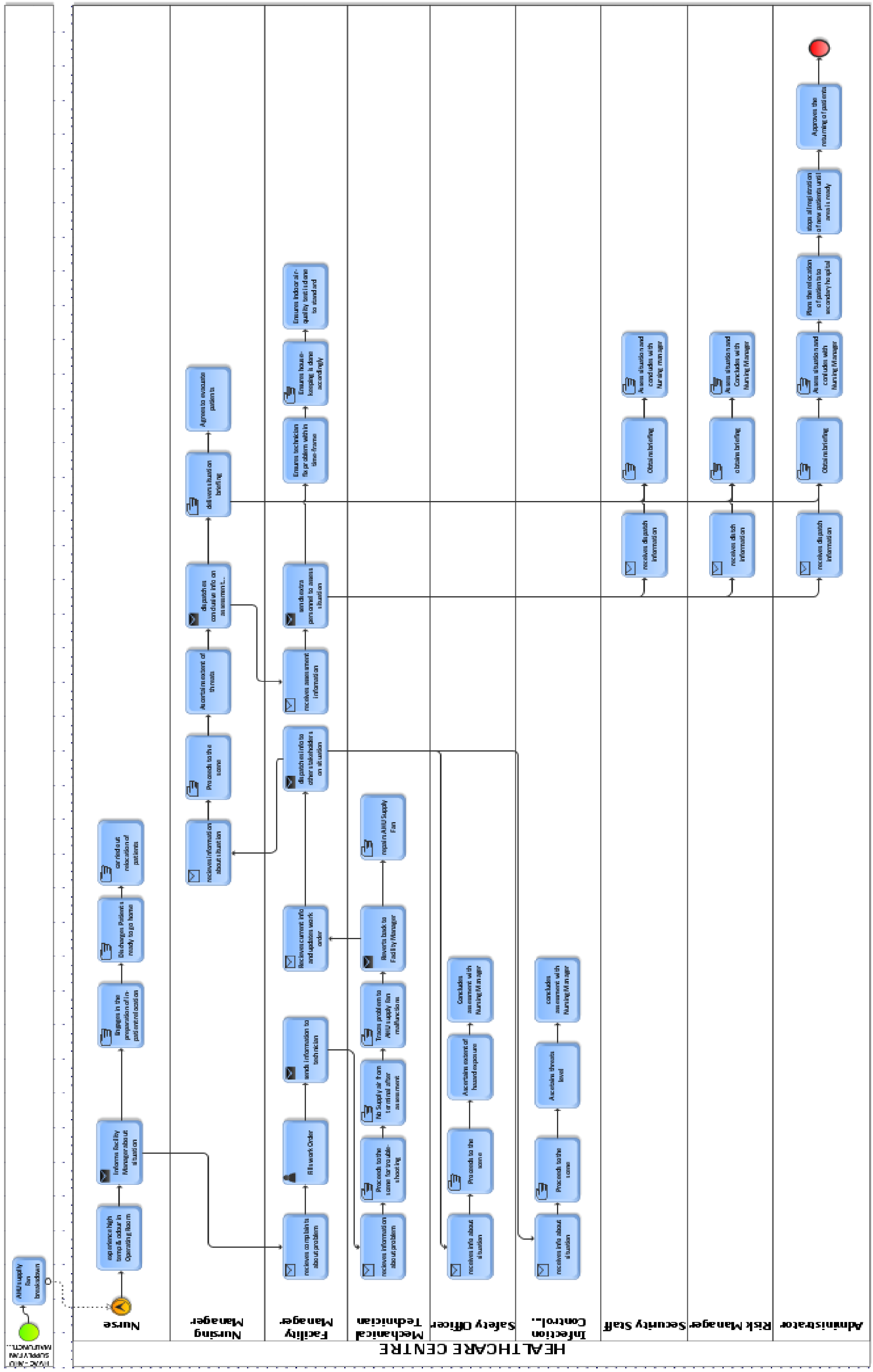

Figure 31: BPMN of AHU Supply Fan Maintenance in Healthcare centre- Are completely Included in Appendix B below

4.4 UML Use-Case Scenarios

From the foregoing, it is quite evident that the UML Use-Case Scenarios would be built from the previous methodology described above. That is to say, the detailed information derived from the elaborated BIM, FMEA and the BPMN would definitely be applied to this UML Use-Case scenario in order to ascertain the information requirements that could support facility management operations reach a swift decisive conclusion of facilities maintenance in healthcare centres. It is evident that the BIM and FMEA where used to construct the alternative flow as it examines the problem and failure causes highlighted in relation to the HVAC system meanwhile the BPMN method is used to develop the basic/main flow of events of the UML Use-Case Scenarios. These use case are made up of several scenarios with the right kind of communications and behaviours between the system and the user. In addition to this, for the scope of this research, the use case analysis is meant to fulfil requirements that should satisfy or support or bring about a measurable value to the actor who happens to be the facility managers or stakeholders who would communicate and interact with the system.

Therefore, the use case implemented in this research is primarily to collate all necessary information requirements that could be used to support facility management operations in healthcare centres. These use cases would be formed on the basis of these use case requirements which includes preconditions, basic/main flow of event, sub flow of event and finally the alternative flow of events. According to (Williams , 2004), the definition of a use case diagram is simply a visual representation of the relation between actors and use cases together that documents the systems intended behaviour. As explained earlier, the actor is the user who wants or desires a function from a system (external stakeholders) while the use case(s) are the things that the system should provide to the user (i.e. facility manager) that would add measurable value to the him, thereby enabling him perform his duty during the operational life of the facility. In this research method, a textual description of the sequence of actions between users and use cases would be elaborated in order to further understand what happens in a use case. That is to say, each use case scenario will be in a documented form plus a diagram, highlighting into details the referenced communications between the actors and the use case in a narrative and diagrammatic manner.

Table 5: Use Case - Temperature Escalation

Use case Name	**Temperature Escalation**
Short Description	This use case actually indicates the outcome of the temperature complaint escalated.
Pre-Conditions	1) The Facility Manager and the Nurse have access to phones and emails. 2) The Facility manager has access to the Building Information Modelling Data of the hospital. 3) The Nurse does not possess direct control to influence the temperature for the patients.
Main Flow of Event	1) The Nurse on duty visits the patients in the Operating Room suite. 2) The Nurse experiences a high level of temperature and odour within the operating room. 3) The Nurse escalates by informing the Facility manager about the high temperature and odour within the operating room. 4) The nurse furnishes the Facility manager with the actual location of the problem room space. 5) The facility manager looks up the Revit BIM model to ascertain the location where the problem space is affected in order to dispatch the mechanical technician to the exact location. 6) The HVAC mechanical technician

	receives the information from the facility manager; goes to the site with the necessary details like the space and unit location where the problem had occurred. 7) The technician finishes **Trouble-shooting of HVAC System**
Alternative Flow of Event	The Facility manager receives an automated alert in email and phone from the remote sensors of thermostat that the internal temperature of the operating room is extremely above the standard indoor air quality. 1) The facility manager sends the HVAC technician to the scene with the required information for trouble-shooting the issue on site (which includes location ID).

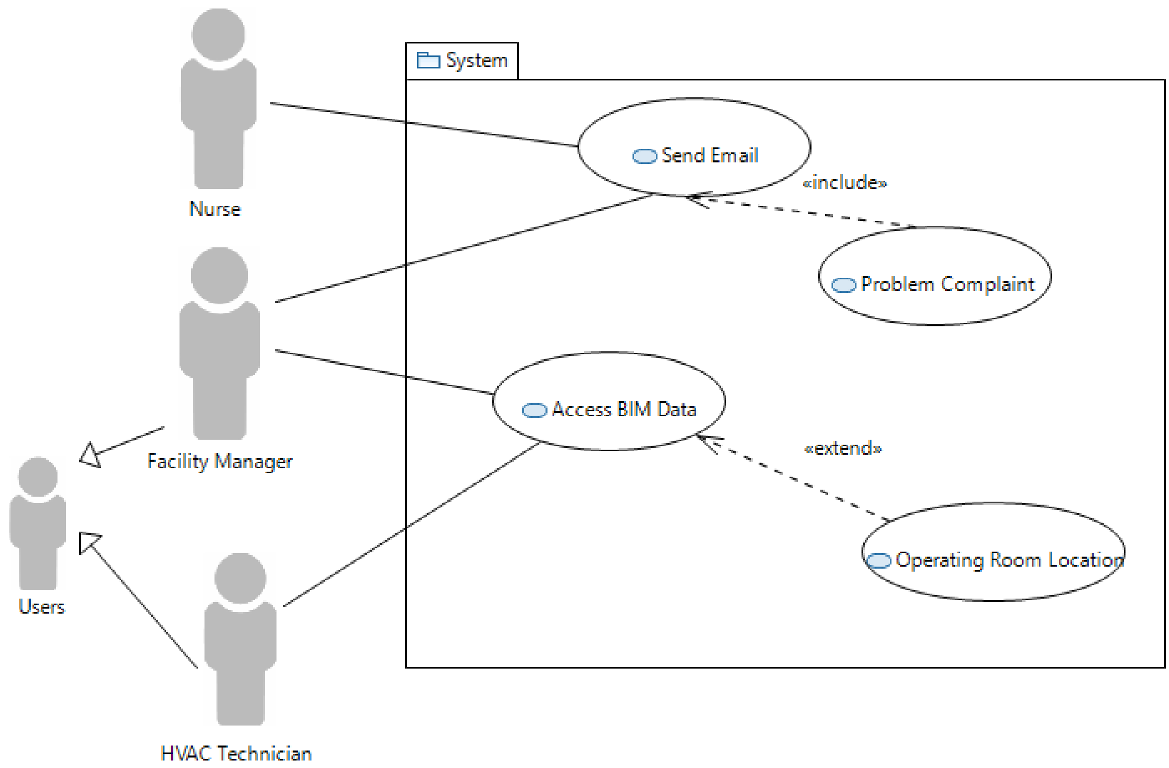

Figure 32: Temperature Escalation Diagram – Check Appendix C for complete details

Table 6: Use Cases and Information Analysis

Use Case	Steps	Information	User	Source
1	2	Temperature & Odour	Nurse	Operation- patient complaint
1	3	Temperature & Odour	Facility Manager	Operation- Nurse escalated complaint
1	4	Location	Facility Manager	Nurse Report
1	5	Location	Facility Manager	Revit BIM
1	6	Location	HVAC Technician	Facility manager Alert, BIM
1	6	Air Handling unit	HVAC Technician	Facility Manager, Mechanical Drawings
1	6	Problem	HVAC Technician	Nurse Report
2	1	Identified Problem	HVAC Technician	Nurse Report/FM
2	2	Location	HVAC Technician	BIM, Mechanical Drawings
2	3	Thermostat offline	HVAC Technician	Technician Observation
2	4	Terminal supplies no air	HVAC Technician	Technician Observation
2	5	Troubleshooting Procedures	HVAC Technician	Technician procedures
2	6	Supply Fan not Working	HVAC Technician	Diagnosing procedures, Observation,

				Mechanical Drawings.
3	1	Problem Documentation	Facility Manager	Nurse Report Update
3	2	Thermostat offline	Facility Manager	Remote sensor Information
3	3	Replacement part availability	Facility Manager	Mechanical inventory
4	1	Identified Problem	HVAC Technician	Facility Manager Work Order report
4	3	Replacement part	HVAC Technician	Mechanical Inventory
4	4	Fixing Procedures	HVAC Technician	Manufacturers Procedural document
4	7	Complete repairs/fixing	HVAC Technician	Work Order Notification
5	1	Condition Update	Stakeholders: Infection Control officer, safety officer and nursing manager	Facility Manager report update
5	3	Damages	Stakeholders	Professional Observation & Assessments
5	4	Schedule repair	Stakeholders	Professional Observation & Assessments

6	3	Damages (atmospheric, physical, patients)	Extra Personnel: Administrator, Risk manager & security staff.	Professional Observation & Assessments
6	4	Patients Evacuation	Extra Personnel: Administrator, Risk manager & security staff.	Assessment Conclusion
7	1	Problem cause	Administrator	Facility Manager report
7	2	Room Condition Assessment	Administrator	Extra personnel Assessment report
7	5	Relocation of Patients	Administrator	Based on assessment report, standard operating procedures of relocation.
8	1	Completed repair	HVAC Technician	Work Order Notification
8	4	Location Cooling	HVAC Technician	Healthcare standard for indoor air quality
8	6	Location restored back	Facility Manager	HVAC Technician update report
8	7	Location restored back	Facility Manager	Personal Observation
8	8	Patient Returning	Administrator	Facility Manager recommendation

9	1	Conditioned air-quality	Administrator	Facility Manager recommendation
9	4	Air-quality conformity	Administrator	Healthcare standard for indoor air quality
9	7	Transfer of patients back	Secondary Hospital	Administrator, transfer procedural observation.

4.5 Summary of result Analysis

From the foregoing in this chapter, the initial Building Information Model data was used to find out the location where the problem had occurred and possible cause(s). Firstly, the schematic view of the HVAC – AHU was drawn in order to ascertain the structural components of the mechanical system. Following the schematic view is the BIM 3D – Layout of this mechanical system, just to reflect the realistic structure of the system and how it serves the Operating room where the problem mostly impacted. Furthermore, a graph-supported IFC interpretation of the HVAC-AHU system was used to demarcate between the central system unit and the terminal system unit in order to be able to trace the IFC component parts of the integral system. Finally, the table that linked the problem space, work order and problem root causes were drawn out to reflect the present state of the BIM result in this research.

Since the problem space and the problem cause where highlighted in BIM, then FMEA was used to take it deeper to ascertain the different threat levels of the of this failure to both clinical and facility operations. That being said, it shows how different responses could be approach given the different type of failures that may have occurred. In order to obtain this information, certain FMEA procedures were to be followed to complete the FMEA phase which includes the drawing out of a flow chart that indicates the total scope of this method. After which the function block diagram was equally designed to indicate the area of the system that should be focused on according to the problem location. Then, the actual FMEA table was made to show the breakdown of failure modes which can affect the entire system.

Meanwhile the process model that was drafted and drawn in BPMN was to indicate the series of steps taken decisively in the entire process of rectifying the problem.

Eventually, from the FMEA and the BPMN plus BIM, the Use-case diagrams were established. Since these use-cases were fully itemized, they were further used to extract the information requirement that could be leveraged by facility management personnel to support the activities carried out in terms of appropriate response to facility related problems in healthcare centres. From table 14, it was a clear indication of the information that was required to address the temperature increase and odour problem that occurred in the operating room, which was traced to be an HVAC supply Fan component failure. The information includes the use case scenarios, the steps within the use case scenarios, the actual activity/phase that takes place, the user responsible for facilitating the activity/phase and lastly, the source where the responsible user should get the information about the activity/phase. All these information goes to support the Facility manager to determine a quick form of response, knowing the parties that are involved in each step.

Chapter Five

5. Conclusions and Future Outlook

Previous studies have shown that facility maintenance operation suffers a great deal due to fragmented and incomplete information between facilities management activities and the primary operations of any business. Lots of wasted down time due to this inadequacy has led to several organizations bankruptcy because of this information exchange and communication lapses. That is to say, information sharing has long been broken into several bits in the facility lifecycle and the operation phase has accounted for a larger part of this issue perhaps, due to its role in the lifecycle of buildings.

It is of paramount importance for facility management staffs in the healthcare industry to ensure that the hospital they are serving benefit from their support as patients and care givers is usually exposed to health concerns and vulnerabilities. This in fact, makes the task of facilities managers of the healthcare industry to be critical as they have to be aware of the normal information disconnection between clinical and facilities personnel themselves. In light of this, facility managers are mandated to keep very complicated systems in operational within the healthcare environment; in such a manner that its maintenance activities will not impact clinical operations. Therefore, in this research, efforts made as elaborated in previous chapters was to show the facilities information requirement that could support facilities maintenance of HVAC systems in healthcare centres, thereby breaking through the barriers of information exchange and communication between clinical staffs and facilities management team alike.

This identified problem of disconnection in information exchange and communication was tested in this research in such a way that reflects the approach for solving a HVAC –AHU supply fan problem. Basically, in response to this issue, this project was carried out to provide facility information requirements for a more efficient and effective method of managing healthcare facility especially when it has to do with areas very crucial like HVAC maintenance.

The BIM-based facility information requirements were used to assist facility management activities and promote required information that would enable facility managers to solve the problems while creating a link between clinical activities and facility management activities. In this research, the facility information requirements approach made the facility manager to consider ways that might assist them to respond to clinical concerns within the healthcare environment without many delays. This swift and decisive response could reduce the effects of the proposed threat level that would have compounded in high monetary equivalent if not addressed promptly.

Furthermore, this chapter simply summarizes the whole link between facility management activities and clinical operations carried out by care givers within the healthcare industry with a solid and fully elaborated case study alongside the method analysis of these links. Although, this research study made use of several modelling methods that resulted into a collection of information that are required by facility management personnel to support the way they work in an effective manner but the required information could be utilized further to form a product model.

5.1 Healthcare Facility Information Requirement Process

The main intention of healthcare facility information requirements process was to give facility managers a broad efficient manner of handling facility information. In actualizing these information requirements, crucial information integration analysis methods were used to describe the connection between facility management information and clinical operations information within a healthcare centre. This then further explains the kind of information that is required by facility and clinical staffs to aid them to respond to facility concerns that might have graven impact of patients' safety. The case study that was applied in this research had to do with the malfunctioning of AHU supply fan in an HVAC system. In this regards, the malfunctioning of the mechanical component of the HVAC system that occurred within the healthcare environment abruptly disrupted clinical services thereby requiring the facility management team to take decisive actions (which includes finding the problem location and cause) and addressing the situation in a swift manner. This research case was described in an algorithm of processes which includes the application of BIM to ascertain the location of where the problem occurred and the corresponding causes to the problem by the use of *case based reasoning*. Going forward, the results derived in the BIM stage was then looked at critically in the failure mode and effects analysis to see the several root causes of the problem itself and the possible threats that was abound within the scope of the problem which might be of a great deal in terms of consequences. Meanwhile, the BPMN was the next following the initial methods of ascertaining the problem, causes and potential threats and possible actions that should be carried out in event of different failure modes. Here, the BPMN was used to show the process of addressing the corrective actions that was taken in combating the problem. The BPMN also indicated the information exchange between facility management activities and clinical operations during the process of solving the problem. And then finally, the BPMN method was used as a guide to determine the several use case scenarios that could be used for further information requirement in future application of a product model development or facility software application; which unfortunately is not within the scope of this research project.

It was evident that the level of response is a function of the main variables which were the actual problem or failure and the location where the problem impacted on directly. These were the connections between the facility management activities and the clinical operations in this event. These two variable types establish the response procedures of both facility management personnel and clinical staffs and management as well. In respect to this, the location of facility management issues and clinical services are inter-connected because in the eventuality of any problem, clinical services that could be impacted by this problem could be easily traced deduced in each case of event. Additionally, the kind of facility oriented problem or issues within the healthcare environment and the location can easily be used to indicate the level of hazardous threats by figuring out the relationship between these two major variables. Therefore, in this research, information requirement includes the use case scenarios, the steps within the use case scenarios, the actual activity/phase that takes place, the user responsible for facilitating the activity/phase and lastly, the source where the responsible user should get the information about the activity/phase. All these information goes to support the Facility manager to determine a quick form of response, knowing the parties that are involved in each step all the way. This requirement apparently shows three (3) variables which can also be used for future events and are - type of **problem**, the **location** and the **cause** of the problem.

5.2 Contributions and advantages to healthcare FM

From the foregoing, the leading aim of this work is to make efficient use of facility information requirements to handle both structural and clinical activities that is related to HVAC maintenance within the healthcare environment. That is to say, the information requirement was rather developed and implemented to connect clinical information and facility information in such a way that it is been helpful to the facility manager in terms of response based on the knowledge derived from the information requirement gathered from the elaborated method analysis. To make things clear, the information requirements is done to fully catch relevant information all through the lifecycle of a facility in order to support facility management activities as it relates to HVAC maintenance of mechanical systems in healthcare centres. With these requirements, information exchange is greatly enhanced and readily available for facility management operations and maintenance phase of any buildings lifecycle.

It also helps to characterize the crucial information that could be required for the optimum response during any facility related eventuality which invariably can improve the exchange of information hence, leading towards an enormous advantage in the long run.

5.3 Future Outlook

As said earlier, to complete the full objective of this work, there is a need to further develop these facility information requirements for HVAC maintenance, and a product model should be developed to ascertain the validity of the obtained information requirements extracted from the developed modelling methods.

Also, the problem scope of this research is looked at from the angle of the Air Handler Unit supply fan which is just one part of several components that makes up the AHU system. Future outlook could be on other components that can lead to different type of problems within the building fabrics of the healthcare centre. For instance, such components might be the heating or cooling coils, filters or even the dampers which happen to be other components that could affect the internal condition of operating rooms and can be a great deal.

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APPENDIX A: Failure Mode and Effects Analysis of Case Study

Table 7: Failure Mode and Effects Analysis

Operational Mode:		Descriptions				
Units of Description		**Desrciption of Failure**			**Effects of Failure**	
ID	Function	Failure Mode	Failure Causes	Detection of Failure	Physical Environment	Health hazard on Patients
270.01	Air Handler Fan	Fan does not supply circulated air.	Power supply is cut-off	HVAC thermostat Sensor in the Operating room and nursing staff escalates the issue	High rise of temperature in the Operating Room(s), odour and/or stuffiness	Increase in discomfort and air-borne infection possibilities like Aspergillums which could worsen patients' health conditions due to vulnerability.

Safeguards		**Severity**	**Likelihood of Occurrence**	**Corrective Actions**
Prevention of Failure	Mitigation of Effects	Low/Medium/High	Low/Medium/High	
Frequent physical inspection of the components should be carried out.	Decongest the Operating room of some staffs and if possible relocate the patient to a similar hospital in order to reduce the risk of exposure to health hazards.	Medium	Medium	Turn off power source and Carry out immediate trouble-shooting of the Air handling Unit supply fan in order to reduce the impact of delays.

270.02	Fan Belt	Fan belt does not roll due to tear.	Fan belt broken.	HVAC Thermostat Sensor in the Operating room plus complaints from staffs about stuffiness and no airflow from ceiling.	High temperature within the Operating room and odour due to stuffiness.	Increase in discomfort and air-borne infection possibilities like Aspergillums which could worsen patients' health conditions due to vulnerability.

Frequent physical inspection of the components should be carried out.	Quickly replace blown fuses by facility management staff.	Low	high	Carry out frequent maintenance of the Air handling Unit with respect to checking fuses frequently and also ensure that fuses are stored up in the facility inventory.

270.03	Fuse	Fuse does not connect the electricity	Fuse is blown	Thermostat sensor does not display	High temperature within the Operating room and odour due to stuffiness.	Increase in discomfort and air-borne infection possibilities like Aspergillums which could worsen patients' health conditions due to vulnerability.

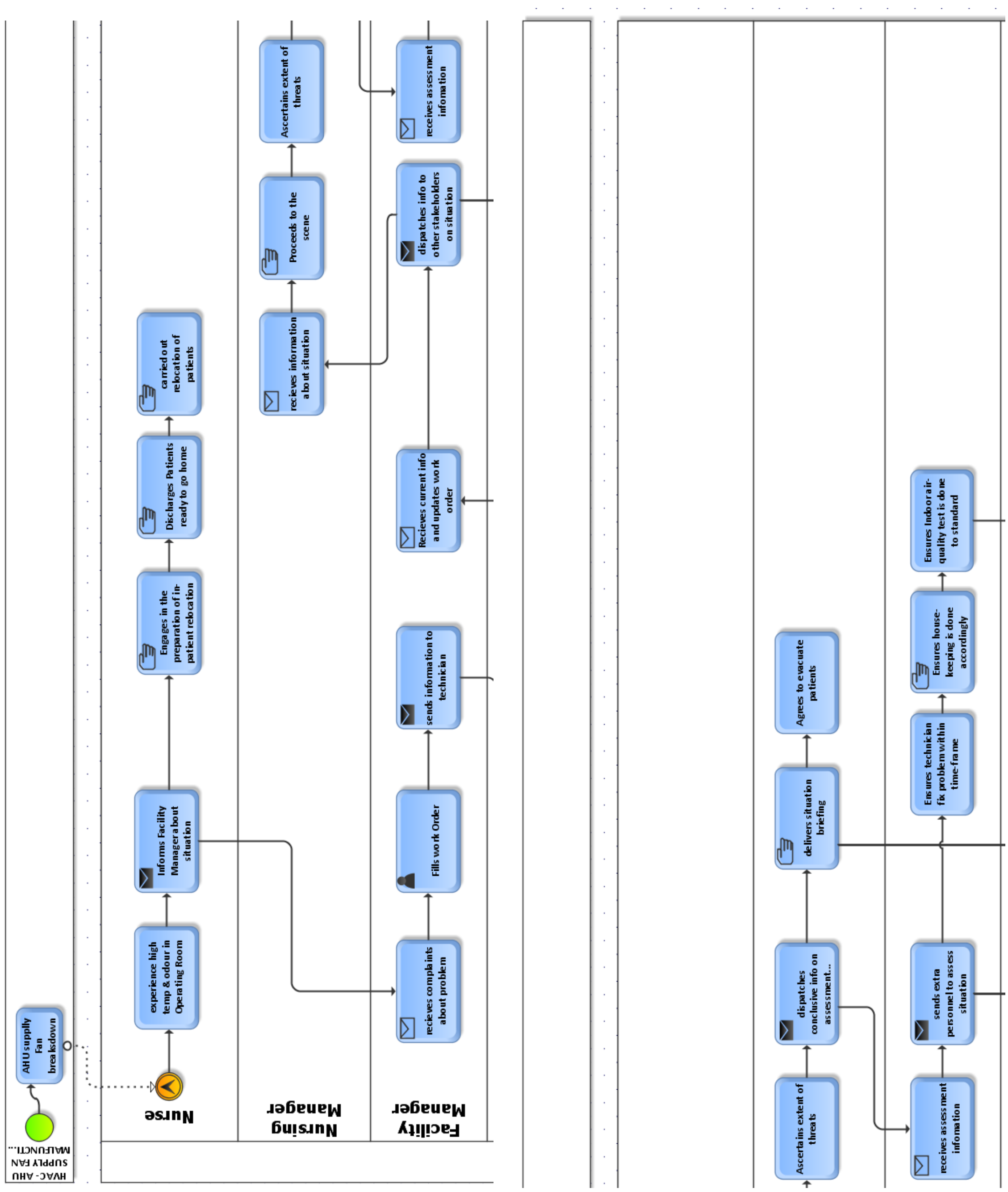
Frequent physical inspection of the components should be carried out.	Quickly replace blown fuses by facility management staff.	Low	high	Carry out frequent maintenance of the Air handling Unit with respect to checking fuses frequently and also ensure that fuses are stored up in the facility inventory.

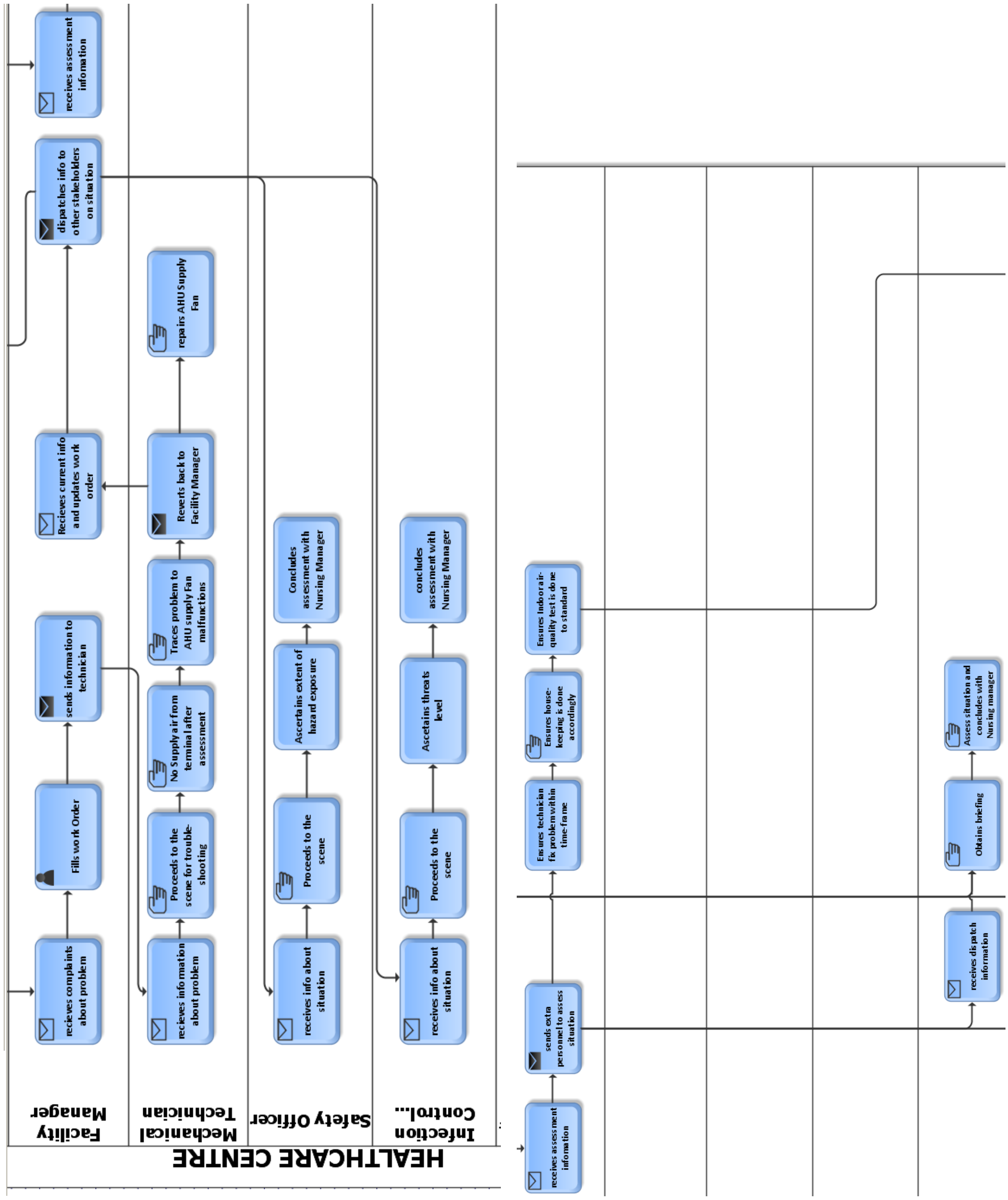
270.04	Fan motor Pulley	Pulley is dis-aligned and causes fan belt to wear off	Loosed Fan motor Pulley.	High temperature in the operating room plus odour complaint from the nursing staff.	Indoor Air quality of the operating room is being affected.	Increase in discomfort and air-borne infection possibilities like Aspergillums which could worsen patients' health conditions.

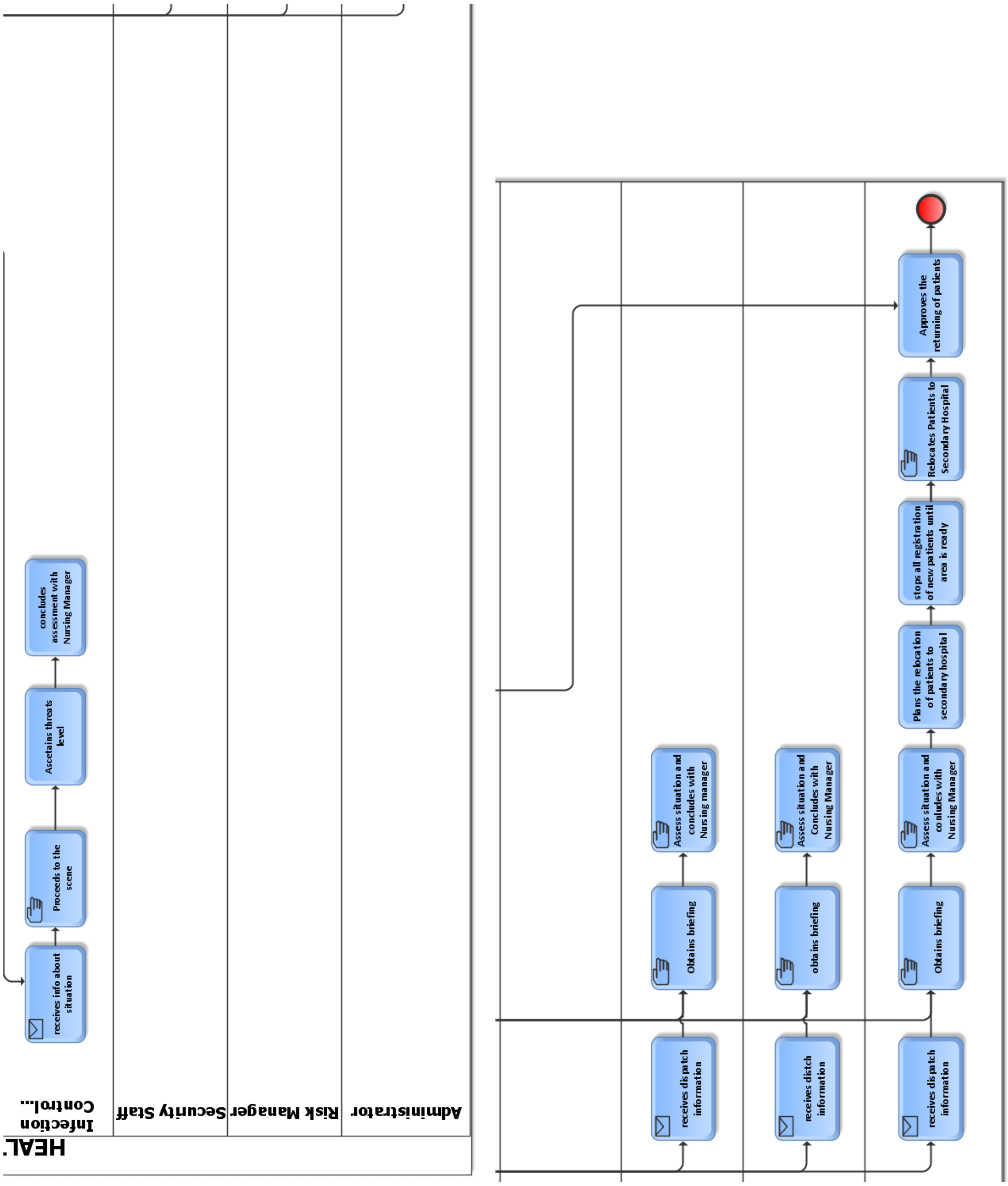
Frequent physical inspection of the components should be carried out.	Decongest the Operating room of some staffs and if possible relocate the patient to a similar hospital in order to reduce the risk of exposure to health hazards.	Medium.	Low.	Send technician to the spot to check the pulley and re-align it (the driver and the driven pulleys). Also, carry out visible inspections of cracks and the effects it might have on fan belts as well.

APPENDIX B: Case Study - Business Process Modelling Notation

Figure 33: BPMN of AHU Supply Fan Maintenance in Healthcare centre




HEALTHCARE CENTRE
Facility Manager
Mechanical Technician
Safety Officer
Infection Control...
recieves complaints about problem
Fills work Order
sends information to technician
Recieves current info and updates work order
dispatches info to other stakeholders on situation
receives assessment information
recieves information about problem
Proceeds to the scene for trouble-shooting
No Supply air from terminal after assessment
Traces problem to AHU supply Fan malfunctions
Reverts back to Facility Manager
repairs AHU Supply Fan
receives info about situation
Proceeds to the scene
Ascertains extent of hazard exposure
Concludes assessment with Nursing Manager
receives info about situation
Proceeds to the scene
Ascertains threats level
concludes assessment with Nursing Manager
receives assessment information
sends extra personnel to assess situation
Ensures technician fix problem within time-frame
Ensures house-keeping is done accordingly
Ensures Indoor air-quality test is done to standard
receives dispatch information
Obtains briefing
Assess situation and concludes with Nursing manager


HEAL
Infection Control...
Security Staff
Risk Manager
Administrator
receives info about situation
Proceeds to the scene
Ascertains threats level
concludes assessment with Nursing Manager
receives dispatch information
Obtains briefing
Assess situation and concludes with Nursing manager
receives distch information
obtains briefing
Assess situation and Concludes with Nursing Manager
receives dispatch information
Obtains briefing
Assess situation and conludes with Nursing Manager
Plans the relocation of patients to secondary hospital
stops all registration of new patients until area is ready
Relocates Patients to Secondary Hospital
Approves the returning of patients

APPENDIX C: UML Use-Case Scenarios

Table 8: Use Case – Troubleshooting of HVAC System

Use case Name	**Trouble-shooting of HVAC System**
Short Description	This use case actually explains the HVAC technicians' actions of reacting to the problem complaint he had received.
Pre-Conditions	1) The Facility Manager and the HVAC technician have access to mobile phones and emails. 2) The HVAC technician has access to the BIM HVAC data where the Unit is located. 3) The HVAC technician equally has a good understanding of HVAC systems.
Main Flow of Event	1) The HVAC technician receives information from the facility manager about the problem to run a check on it. 2) The HVAC technician proceeds to the location where the problem is located. 3) The technician arrives at the scene and finds out the thermostat is gone off in the operating room. 4) The technician diagnoses the HVAC unit and finds out the air terminal supplies no air. 5) The technician traces the ducts up to the HVAC – AHU mechanical room. 6) The HVAC technician discovers that the Supply Fan was not working.

	7) The technician reverts back to the facility manager who **Updates Work Order**.
Alternative Flow of Event	The HVAC technician notices that the Supply Fan belt was broken thereby not supplying unit with conditioned air. 1) The HVAC technician reverts back to the facility manager who then enters the current information in the work order. 2) The technician also notifies the nurse around that the AHU needs to be fixed. 3) The facility manager thereby fills and **updates the work order**.

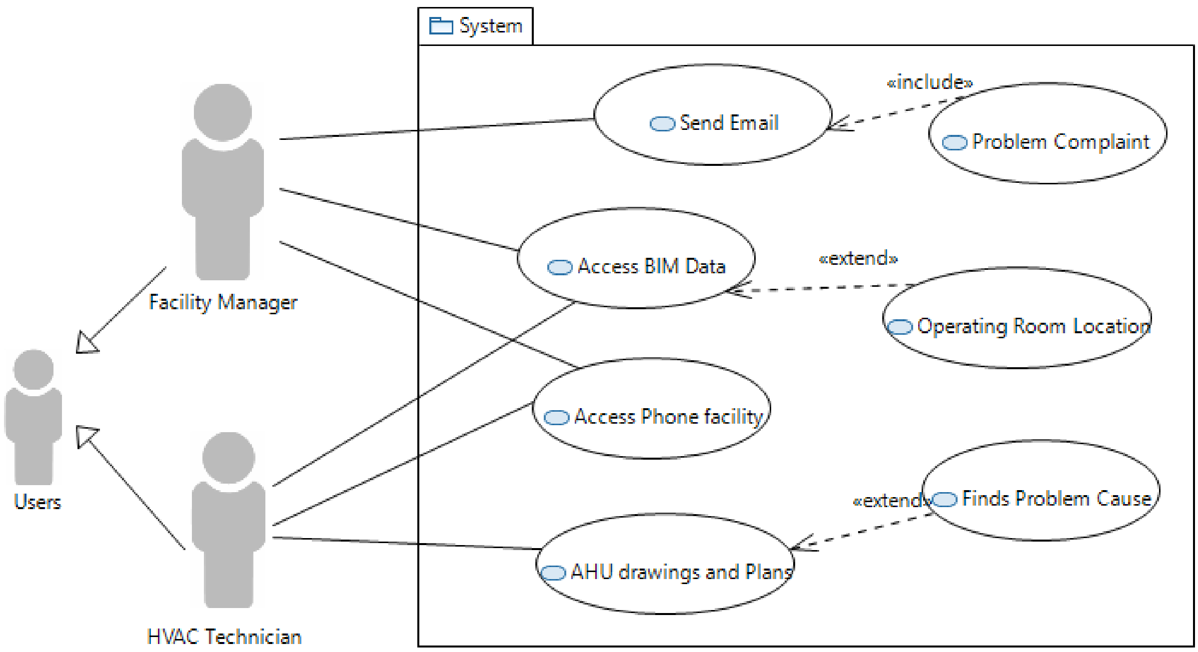


Figure 34: Troubleshooting of HVAC systems Diagram

Table 9: Use Case - Update Work Order

Use case Name	**Work Order Update**
Short Description	This use case actually explains the process of updating the work order by the facility manager.
Pre-Conditions	1) The Facility Manager has access to the Nurse on duty by email or phone. 2) The facility manager has access to the remote HVAC thermostat in the operating room. 3) The HVAC technician equally has access to the facility manager.
Main Flow of Event	1) The facility manager, records information related to the problem identified in the operation room by the nurse. 2) The facility also realizes the thermostat was not reading remotely. 3) The facility manager calls the attention of the mechanical store keeper about the needed parts to be replaced in the AHU unit. 4) The facility manager dispatches the updated information on the work order to other parties especially the nursing manager. 5) The technician finishes the use case **fixing of Unit**.

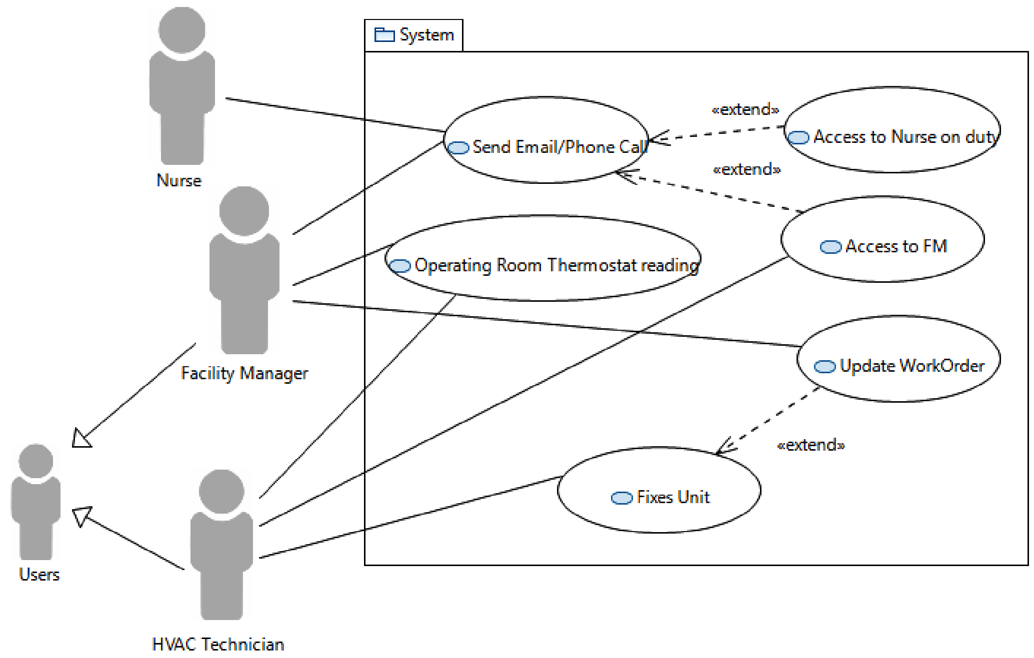


Figure 35: Update Work Order Diagram

Table 10: Use Case- Fixing of Units

Use case Name	**Fixing of Unit**
Short Description	This use case actually explains the process of the HVAC technician fixing the AHU system.
Pre-Conditions	1) The technician has access to the parts that requires to be changed. 2) The technician has a good knowledge of accessing the AHU unit. **3)** The HVAC technician equally has access to the BIM data of AHU unit plans.
Main Flow of Event	1) The technician has the work order information. 2) The technician checks for the availability of precise parts. 3) The technician obtains the part that required. 4) The technician accesses the location and observes all protocols stipulated by the manufacturer before replacement. 5) The technician replaces the part that needs to be changed (supply fan). 6) The technician verifies that the AHU system is fixed and back to work again.

	7) The technician furnishes the facility manager that AHU is fixed and back to work as normal again thereby updating the work order.

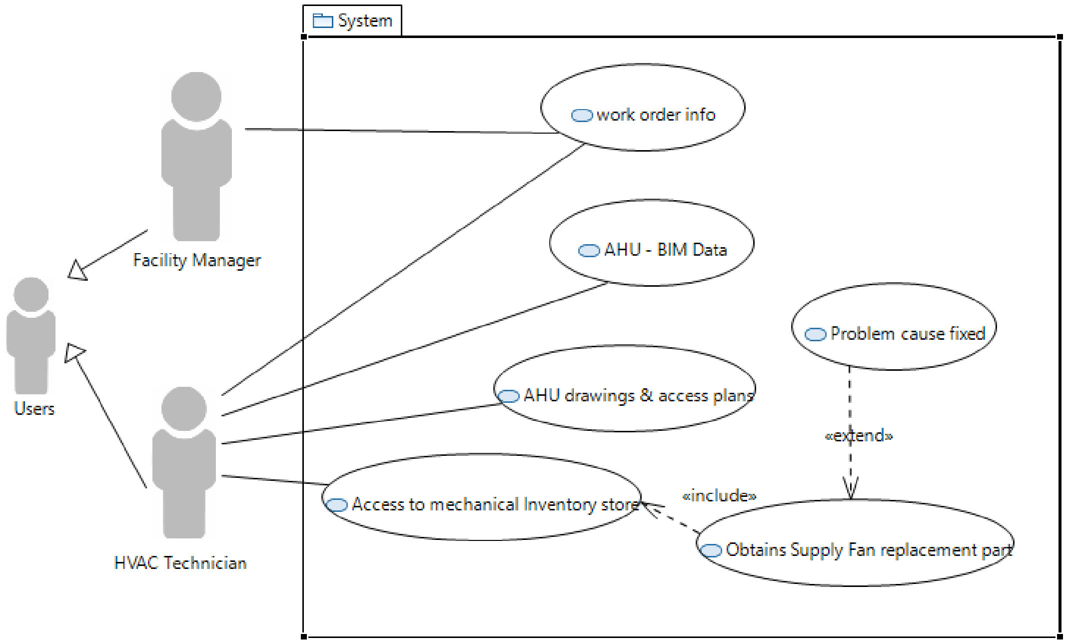


Figure 36: Use Case - Fixing of Unit

Table 11: Use Case - Initial Assessment

Use case Name	**Initial Assessment**
Short Description	This use case actually explains the initial assessment process that took place in the scene.
Pre-Conditions	1) The nursing manager, safety officer and infection control officer were able to quantify the extent of damage this would cost the healthcare centre. 2) The nursing manager, safety officer and infection control officer could also schedule a repair approach according to their conclusion.

Main Flow of Event	1) The stakeholders received the updated work order condition from the facility manager. 2) The stakeholders proceeded to the scene. 3) The stakeholders critically assessed the situation and level of damage to the atmosphere and the AHU system. 4) The stakeholders reached for a unanimous schedule of repair. 5) The stakeholders concluded with the nursing manager to update the facility manager on their observation and the facility manager **dispatches extra personnel.**

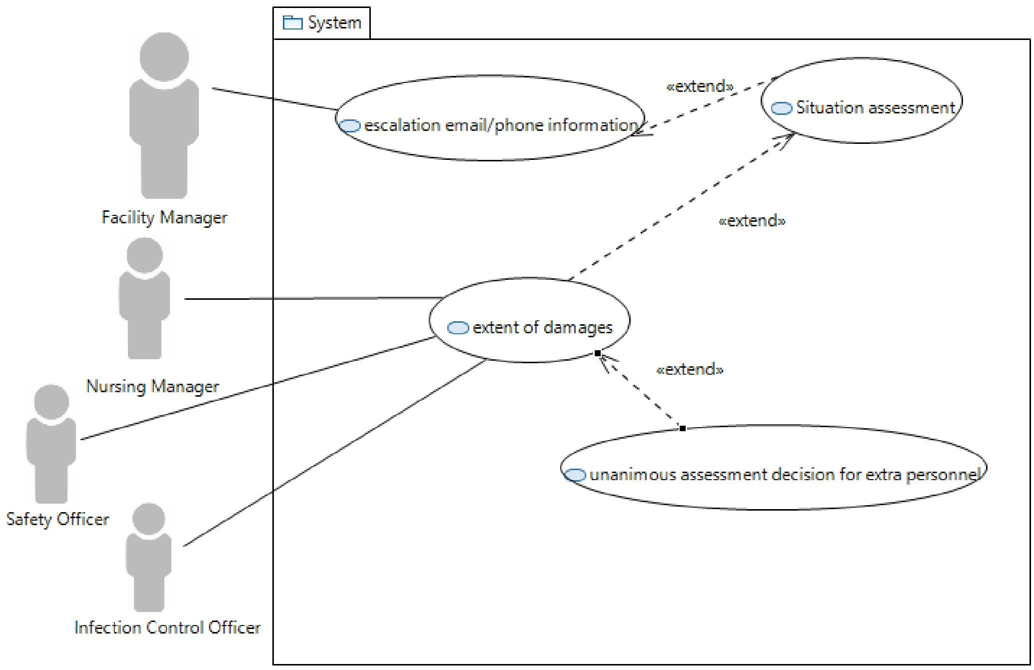


Figure 37: Initial Assessment Diagram

Table 12: Use Case - Dispatches Extra Personnel

Use case Name	**Dispatches Extra Personnel**
Short Description	This use case actually explains the process of calling for extra personnel to proceed to the scene according to the information obtained from the initial assessment of earlier stakeholders.
Pre-Conditions	1) The security officer, Risk manager and administrator have access to the nursing manager. 2) The nursing manager has all necessary information about the present condition of the issue before meeting other for briefing. 3) The security staff, risk manager and administrator have the knowledge to assess the situation for decision making.
Main Flow of Event	1) Extra stakeholders received the dispatched information from the facility manager. 2) The stakeholders proceeded to meet with the nursing manager for briefings. 3) The stakeholders critically assessed the situation and level of damage to the atmosphere and the AHU system. 4) The stakeholders reached for a unanimous decision to prepare for evacuation as the temperature continues to increase. 5) The stakeholders concluded with the **administrator to evacuate**

	this area in total response.

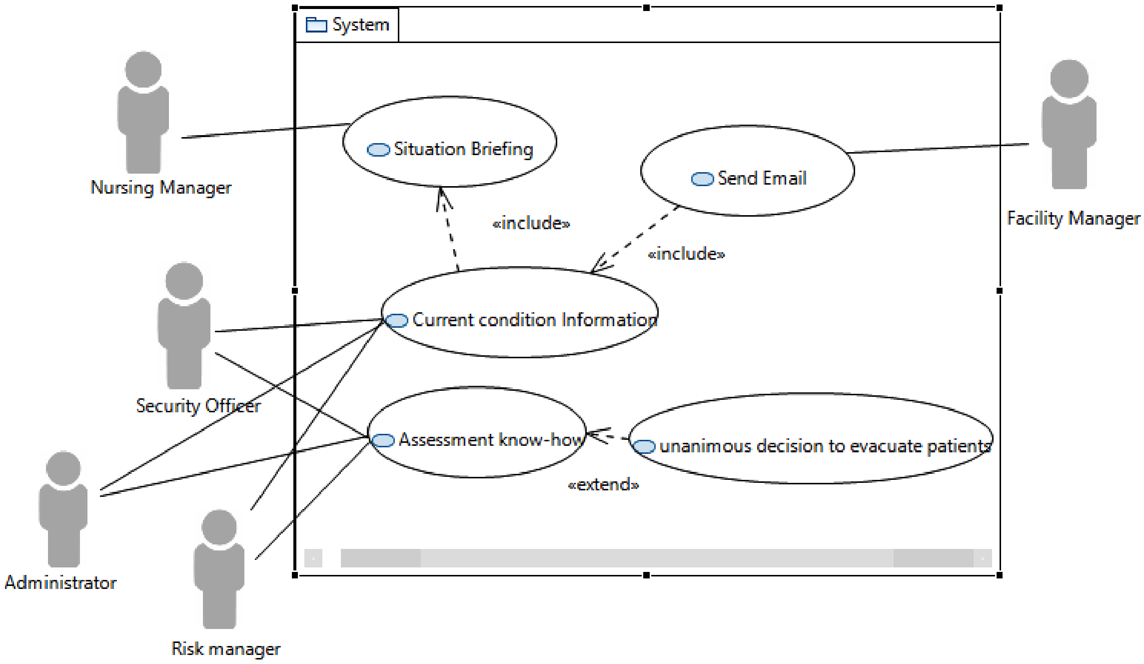


Figure 38: Dispatches Extra Personnel Diagram

Table 13: Use Case - Administrators Decisive Reaction

Use case Name	**Administrators Decisive Reaction**
Short Description	This use case actually explains the reactive decision taken by the hospital administrator to move out the patients in the operating room.
Pre-Conditions	1) The Administrator has prior agreement with secondary hospitals should a case similar for an emergency arises. 2) The Administrator and the security staff could move the patients to the secondary hospital in a safe and effective manner. 3) The Administrator is aware that the secondary hospital has

	adequate space for the transferred patients.
Main Flow of Event	1) The administrator was informed by the facility manager about the situation within the operating room and the HVAC component failure. 2) The Administrator realizes from the meeting with other stakeholders that the operating room will be too hot for patients given the time of HVAC repair. 3) The Administrator decides to move out the in-patients. 4) The administrator stops the registration of patients into the operating room. 5) The Administrator plans the relocation of patients according the standard operating procedures of relocation which includes their records most importantly. 6) The Administrator relocates the patients accordingly with full support of the security and risk manager. 7) The administrator decides to wait until the **system gets back on Track.**

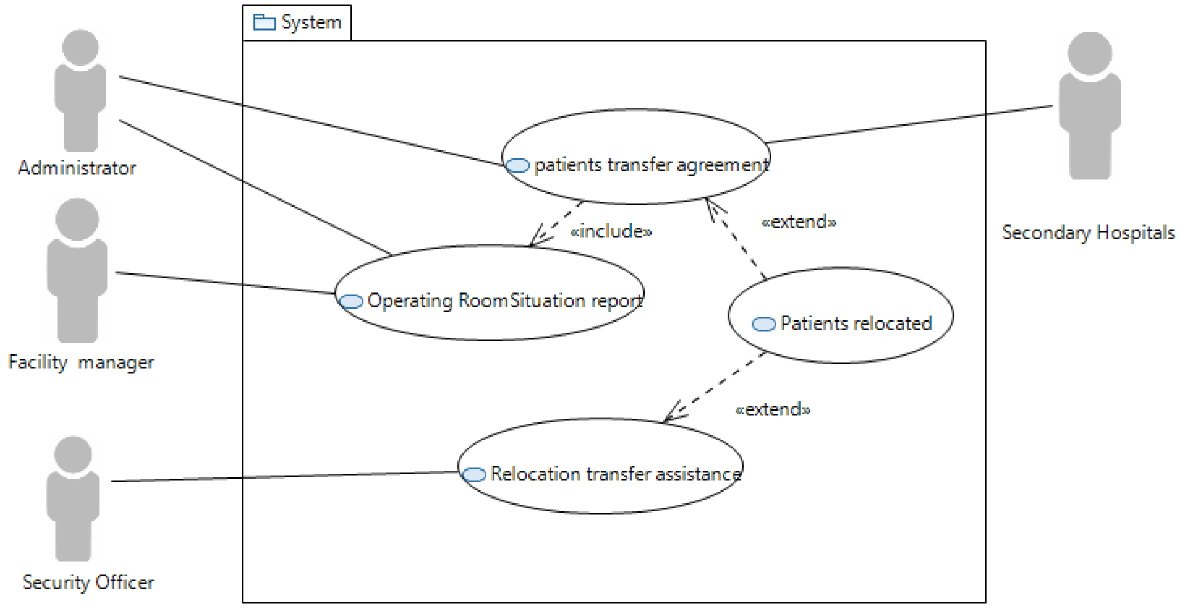


Figure 39: Administrators Decisive Action Diagram

Table 14: Use Case - System back on Track Diagram

Use case Name	**HVAC System back on Track**
Short Description	This use case actually looks at the process for the bringing back the HVAC – AHU system back on track again.
Pre-Conditions	1) The HVAC technician knows how to bring back the AHU system on track remotely.
Main Flow of Event	2) The technician begins to work on the AHU system having received the replacement parts. 3) The technician fixes the HVAC-AHU system. 4) The technician follows the procedures of cooling the location according to the regulated indoor air-quality standard. 5) The technician carried out the cooling of the space over a 24-

	hour period to be sure the air pathogens are gotten rid-off. 6) The technician informs the facility manager that the system is fixed and okay plus the indoor air quality in the operating is okay as well. 7) The facility manager verifies by himself that everything is in order. 8) The facility manager informs the administrator to **relocate patients back.**

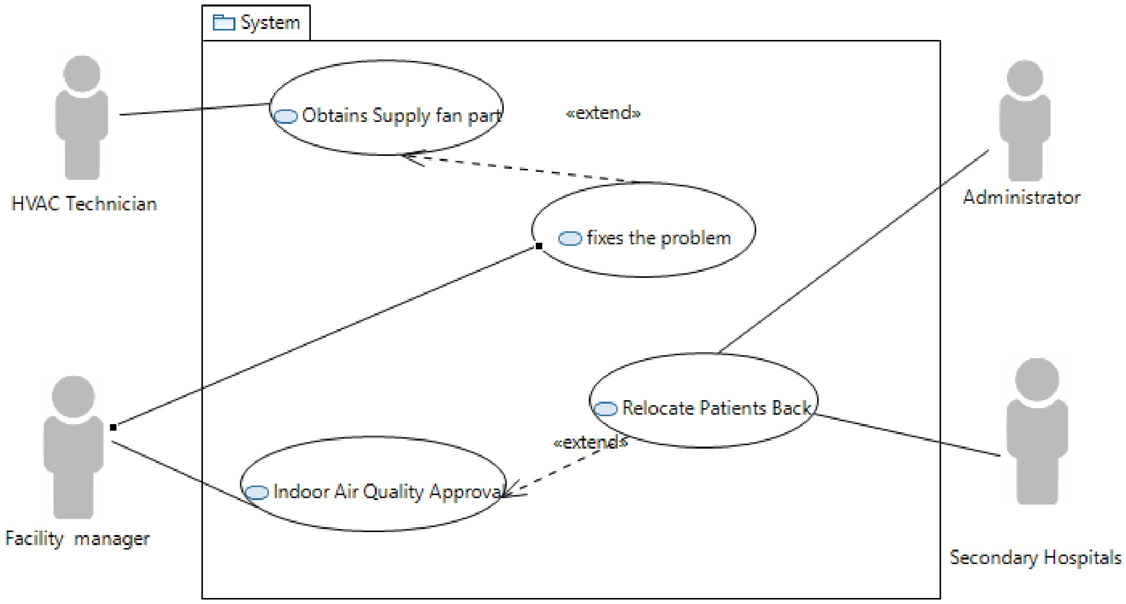


Figure 40: System Back on Track Diagram

Table 15: Use Case - Relocate Patients Back

Use case Name	**HVAC System back on Track**
Short Description	This use case actually explains the process for bringing back the patients from secondary hospital by the administrator.

Pre-Conditions	1) The Administrator was fully furnished with the information from the indoor air-quality test performed by the facility manager.
Main Flow of Event	2) The Administrator obtains full details of the indoor air-quality of the operating room in health centre. 3) The Administrator has prior knowledge about the indoor air-quality standard and verifies the conformity. 4) The Administrator confirms the conformity. 5) The Administrator approves the relocation of the patients back to the HealthCare centre. 6) The Administrator informs the secondary hospital administration about the relocation of patients back to their original hospital. 7) The patients were transferred back to their original places in the operating room of the healthcare centre.

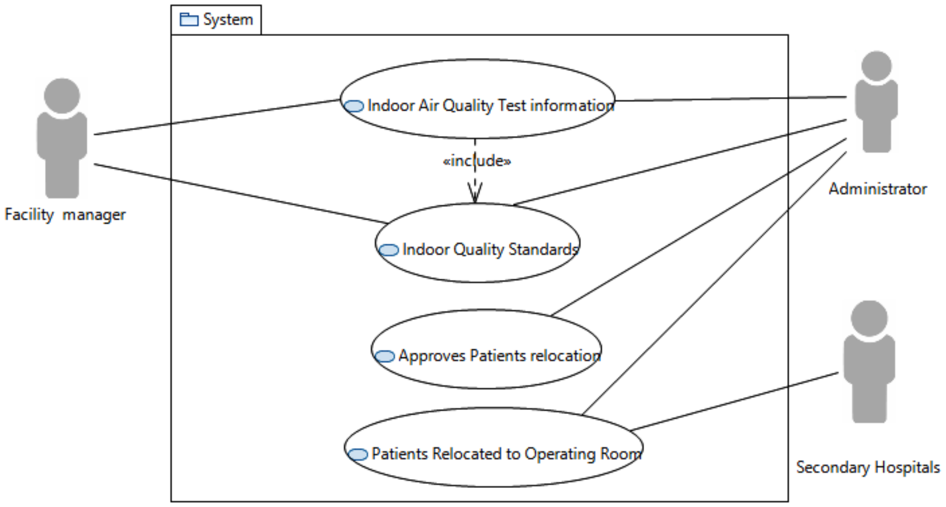


Figure 41: Relocate Patients Back Diagram