The Use of a BIM-Based Framework to Support Safe Facility Management Processes

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ACADEMIC ABSTRACT

According to the United States Bureau of Labor Statistics, 293 people lost their life from 2008-2012 in the field of Facility Management (FM). In that same timeframe, private employers recorded 98,420 cases of occupational injuries and illness, with 26,190 cases requiring a minimum of 31 days away from work. Workers in this field are at constant risk of electrical shock, falls, crushing, cuts, and bruises and as a result, have a much higher rate of injury and illness than the national average.

Case study analysis confirms that many of the recorded accidents could have been avoided had the victim followed appropriate hazard mitigation steps to safely execute a facility repair and maintenance task, defined in this research as safety protocol. Currently, safety related information is conveyed to FM staff through training seminars, O&M manuals, plans & specifications, database storage, safety meetings, and safety literature. This information, although comprehensive, often remains fragmented among multiple resources and is left up to the worker's discretion whether the information is relevant. Research has shown that the more time and effort, known as inconvenience, an individual must spend obtaining information, the less likely they are to retrieve the information and obey the stated warnings.

This research focuses on the identification, categorization, transference, and delivery of safety related information applicable to facility management staff. This is executed by, obtaining safety inputs through various mechanisms of data collection, categorizing the safety inputs, transferring the information utilizing existing BIM-based software and research methods into a data storage repository, and designing a data retrieval and processing system (DRPS), integrated into the repository to interact with the data. The DRPS adds structure and relationships through a UML Class Diagram and Sequence Diagram. Additionally, standardized safety properties are developed for asset groups using the Asset Safety Identification Tool (ASIT). Finally, a conceptual graphical user interface (GUI) is developed to represent the interaction between the DRPS and the FM Worker. By combining the DRPS with a GUI, a FM worker can efficiently interact with a singular repository for safety information, eliminating the need to reference multiple resources in order to obtain comprehensive safety information. The goal of this research is to mitigate the fragmentation and timing inefficiencies within safety related information retrieval by developing a BIM-based framework to categorize, consolidate, and deliver job specific safety information, eliminating the need to reference multiple documents in order to develop a comprehensive, task specific safety plan.

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PUBLIC ABSTRACT

According to the United States Bureau of Labor Statistics, 293 people lost their life from 2008-2012 in the field of Facility Management (FM). In that same timeframe, private employers recorded 98,420 cases of occupational injuries and illness, with 26,190 cases requiring a minimum of 31 days away from work. Workers in this field are at constant risk of electrical shock, falls, crushing, cuts, and bruises and as a result, have a much higher rate of injury and illness than the national average.

Data analysis confirms that many of the recorded accidents could have been avoided had the victim followed appropriate hazard mitigation steps to safely execute a facility repair and maintenance task. Currently, safety related information is conveyed to FM staff through training seminars, operations & maintenance manuals, plans & specifications, virtual training, safety meetings, and safety literature. This information, although comprehensive, often remains fragmented among multiple resources and is left up to the worker's discretion whether the information is relevant. Research has shown that the more time and effort an individual must spend obtaining information, the less likely they are to retrieve the information and obey the stated warnings.

This research focuses on the identification, categorization, transference, and delivery of safety related information applicable to FM staff. This is executed by, obtaining safety inputs (categorized information) through various mechanisms of data collection, organizing the safety inputs, transferring the information utilizing existing engineering software and research methods into a computer based data storage repository, and designing a data retrieval and processing system (DRPS), integrated into the data storage repository to interact with the data. The DRPS adds structure and relationships through computer programming, using a Unified Modeling Language (UML) Class Diagram and Sequence Diagram. Additionally, standardized safety properties are developed for FM assets (operations equipment) using the Asset Safety Identification Tool (ASIT). Finally, a conceptual computer interface (GUI) is developed to represent the interaction between the DRPS and FM Worker. By combining the DRPS with a GUI, a FM worker can efficiently interact with a singular repository for safety information, eliminating the need to reference multiple resources in order to obtain comprehensive safety information. The goal of this research is to mitigate the fragmentation and timing inefficiencies with retrieving safety information by developing a computer based framework to categorize, consolidate, and deliver job specific safety information, eliminating the need to reference multiple documents in order to develop a comprehensive, task specific safety plan.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1. Background

Buildings in the United States and around the world are becoming increasingly complex, utilizing sophisticated technologies for communication and operational control. The role of facility management (FM) staff is critical to the planning, maintaining, and managing of these complex facilities (Global FM 2012). As skilled professionals, FM staff use knowledge in multiple disciplines such as electrical, mechanical, and plumbing to ensure the functionality of the built environment (International Facility Management Association 2013). Often, the complexity of the systems will dictate the requirements for FM staff and the expertise areas that are required for the management of the facility.

Due to the maintenance and repair requirements of these facilities, workers in this field are at high risk of injury including, electrical shock, falls, crushing, cuts, and bruises. As a result, FM workers in the United States have a much higher rate of injury and illness than the national average when compared to all other employment fields (See *Figure 1*) (Bureau of Labor Statistics 2014a). In the five years from 2008 through 2012, 293 people lost their life in the field of Facility Management, also referred to as General Maintenance and Repair (Bureau of Labor Statistics 2009a; Bureau of Labor Statistics 2010a; Bureau of Labor Statistics 2011a; Bureau of Labor Statistics 2012a; Bureau of Labor Statistics 2013a). This number accounted for roughly 1.3% of all occupational fatalities in the United States and has shown an increase of 64% from 2008 to 2012. In that same timeframe within the private sector, FM employers recorded 98,420 cases of occupational injuries and illness, with 26,190 cases requiring a minimum of 31 days away from work (Bureau of Labor Statistics 2009b; Bureau of Labor Statistics 2010b; Bureau of Labor Statistics 2011b; Bureau of Labor Statistics 2012b; Bureau of Labor Statistics 2013b). Case study analysis of the Fatality Assessment and Control Evaluation Program (FACE), issued by The National Institute of Occupational Safety and Health (NIOSH), confirms that many of the recorded accidents could have been avoided had the victim followed appropriate hazard mitigation information to safely execute the facility repair and maintenance (FRM) task.

To mitigate some of the risks associated with FRM tasks and to comply with many federal, state, and local laws, organizations provide job specific training and numerous safety specific documents to protect their FM employees (Occupational Safety and Health Administration 1998). These are proven and effective methods for the protection of staff, but require the information to be utilized comprehensively. In other words, no single training seminar or safety document supersedes the others. This requires the FM worker to comprehend all the safety information collectively and enact the applicable safety protocol with each

FRM task. With the majority of onus on the worker's interaction with the safety information, it is not surprising that human error is the cause of 70-80% of all operational accidents (Leveson 2004).

Incidence Rates[1] of Nonfatal Occupational Injuries and Illnesses, Private Industry (Per 10,000 Full-time Workers)
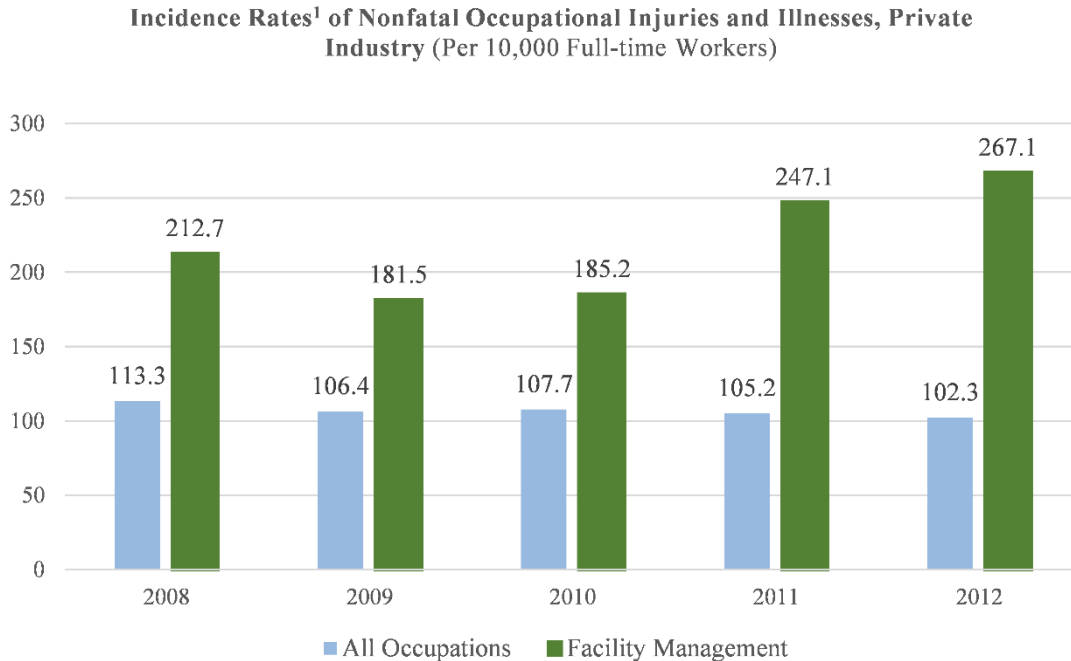
[1] Incidence rates represent the number of injuries and illnesses per 10000 full-time workers and were calculated as: (N / EH) X 20000000 where N = number of injuries and illnesses EH = total hours worked by all employees during the calendar year 20000000 = base for 10000 full-time equivalent workers (working 40 hours per week 50 weeks per year).

Figure 1: Comparison of Incidence Rates (Bureau of Labor Statistics 2009b; 2010b; 2011b; 2012b; 2013b)

Comprehensive safety information is often available within an organization; however, this information is often fragmented among multiple resources that would need to be referenced prior to a FRM work activity (Goedert and Meadati 2008; Lucas 2012). Research has shown that the more time and effort an individual must spend obtaining information, the less likely they are to retrieve the information and obey the stated warnings (Godfrey et al. 1985; Wogalter et al. 1989; Zeitlin 1994). Conversely, minimizing the amount of time and effort to the lowest possible level of information retrieval, has shown a much stronger likelihood of safety protocol implementation (Zeitlin 1994). This information retrieval is vital to the safety of facility management workers as daily tasks are often time sensitive and can require quick reaction in order to place the facility or critical equipment back into functioning condition.

Within the field of FRM, there are two types of maintenance activities that can take place on a daily basis, reactive maintenance or preventative maintenance. Reactive, or breakdown maintenance, requires the replacement or repairing of faulty parts and/or components. This type of maintenance is estimated to account for roughly 34% - 45% of all maintenance activities (Blache 2010; Maintenance Assistant Inc. 2014). Reactive maintenance places a substantial burden on FM staff as a number of organizational disadvantages arise when this type of maintenance is necessary, including, direct and indirect costs of repair, equipment downtime, and interference with planned work. Additionally, the pressure to mitigate these disadvantages as quickly as possible creates safety issues by requiring staff to work under pressure to get the systems running without delay (Maintenance Assistant Inc. 2014).

Preventative or planned maintenance uses regular system and equipment checks on fully functioning assets or facilities to lessen the likelihood of failure. This type of maintenance activity is certainly more desirable to FM staff as preventative maintenance allows for planning of resources and strategy; however, to many organizations, this type of maintenance activity has also become a substantial issue. As with many industries, the financial crisis played a significant role in how FM staff managers and organizations allocated resources. During this time period, facility managers were tasked with cutting costs while keeping critical equipment online and functioning. The results of this mandate were staff reductions, limited funding, and deferred maintenance practices (Gager 2014; Harris and Rygielski 2014), creating a substantial backlog of maintenance needs.

Whether FM staff are reactively trying to repair a disabled asset or proactively maintaining a backlog of equipment needs, the requirement to complete work activities as quickly as possible is a daily occurrence. Working under the stress of too many work orders and short deadlines results in rushing, which has been shown to be directly correlated to occupational injuries and fatalities. According to The Lawrence Berkley National Laboratory (2012), "Injuries due to time pressure are most often the result of a conscious or semi-conscious decision on the worker's part to circumvent a known preventative measure to a known safety hazard in the interest of getting the task done on time or rushing to keep ahead of a process following close behind." The inconvenience of having to retrieve uncategorized safety related information from a number of fragmented sources, retards the FRM task, requiring time sensitive activities to be rushed, and often distracting attention from hazards that would normally be recognized.

Exploring which contract entities input safety data, when the data are presented, where it is stored, and how it is extracted, provides insight into the fragmentation of current market safety protocol. This research explores a potential solution to mitigate the fragmentation of safety information, improving the reference

time and required effort, by providing job specific safety protocols at the lowest possible level of information retrieval through the use of a singular BIM-based framework. The framework will act as an intermediary between the stored job specific safety protocols and the FM worker assigned to the task.

1.2. Safety Information Sources

Information that is applicable to the safe maintenance of a facility comes from a number of sources throughout a building's lifecycle. The information is often presented by the contract entities, through a number of contract required documents within a construction project. *Figure 2* presents a number of examples of facility management applicable safety information and the typical source location of that information at the completion of a project, while *Figure 3* presents at what point in the building's lifecycle that information is typically developed. To safely execute a facility management task, a FM worker may need to compile any number of the documents shown in *Figure 2* to create a comprehensive safety protocol.

Figure 2: Applicable Safety Information Present in Multiple Sources
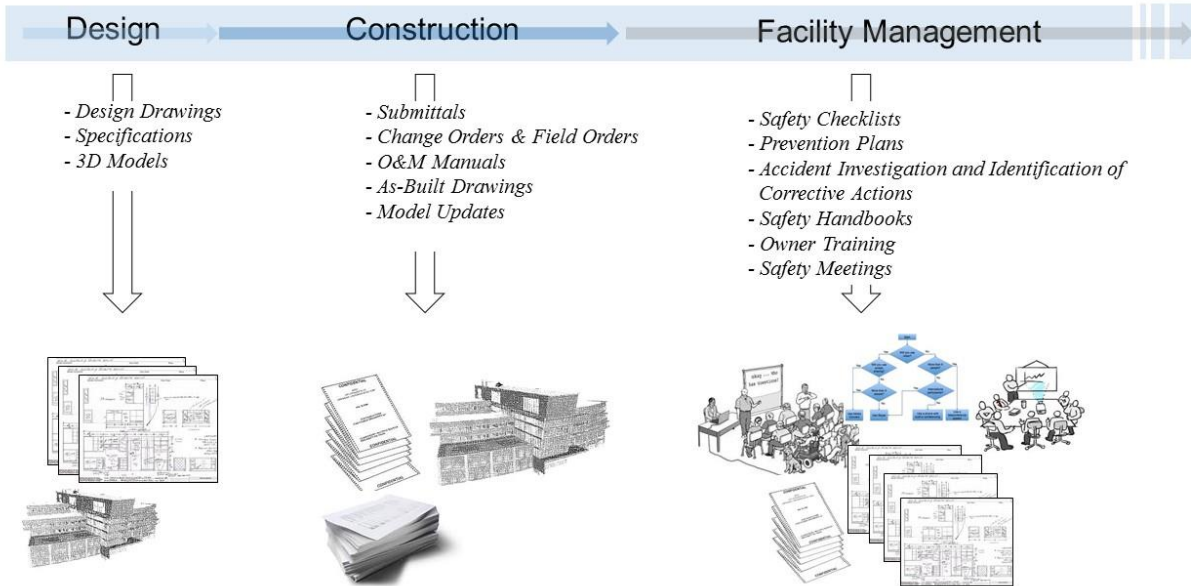
Figure 3: Safety Documentation Sources Occurring throughout the Facility Lifecycle

When architects and/or engineers (A&E) begin to design a building, a number of safety decisions are being made. The routing of power, proximity of disconnects, the number of isolation valves, the elevation of equipment components, and many other considerations, all affect the maintenance requirements during the facility management phase. A conscious understanding of this cause and effect and the subsequent design in support of downstream lifecycle phases is known as Prevention through Design (PtD) or Design for Safety (DfS) (Gambatese et al. 2008; Ku and Mills 2010; Prevention through Design: Design for Construction Safety 2014). The use of PtD/DfS is a powerful tool to improve accident mitigation; however, has historically been focused on the construction phase and less on facility management.

By using PtD/DfS for the FM phase, some hazards can be mitigated (e.g. using a chain wheel for valves at high elevation). Other safety hazards are inherent to the work activities or cannot be mitigated due to site restrictions, process restrictions, congestion, and the like. These hazards will be present despite any design considerations (e.g. electrocution risk associated with high voltage gear). Regardless of the nature of the hazard, the safety concerns/considerations that are made by the A&E will impact the maintenance requirements of the facility.

Along with the considerations made by the design team, the capturing of supplier/contractor procurement decisions within a project could also play a significant role in the development of FM safety protocols. Contractor selection of a manufacturer for procurement of materials and/or equipment results is a substantial amount of applicable safety information that is presented through submittals and O&M manuals. Information such as maintenance cycles, maintenance protocol, required tools, and contact information, all play a role in the downstream development of a safety protocol. Recently, with a focus on BIM-FM, FM personnel have become involved in projects during the design and construction phase in order to aid in this type of decision making. This is often achieved through specific equipment specifications or collaborations with suppliers/contractors.

In addition to project specific information, safety information applicable to the facility management staff will come from organizational policies and procedures. Through safety meetings, literature, manuals, and legal precedence, the internal requirements for the maintenance of a facility plays an integral part in the development of safety protocol. As the employer of facility management staff, the owner/facility manager is ultimately responsible for the safe maintenance of the facility. Failure to properly educate staff or maintain a safe working environment could result in worker's compensation claims and/or litigation (Commonwealth of Massachusetts 2014).

1.3. Fragmentation of Relevant Safety Information to Support Facility Management

Research has shown that the more time it takes a person to obtain safety information, the less likely that individual is to reference or retrieve the information and obey the stated warnings (Godfrey et al. 1985; Wogalter et al. 1989; Zeitlin 1994). In facility management, safety information is fragmented among multiple resources, developed at various points in a project's lifecycle, creating inefficiencies in the procurement of information as shown in *Figure 2* and *Figure 3*. When a piece of equipment requires maintenance or repair, the FM worker will need to address all of the safety concerns that are applicable to that equipment. This will likely require referencing multiple documents to identify comprehensive safety concerns surrounding the task. The inconvenience of having comprehensive safety information scattered through multiple documents, coupled with the often present time sensitivity inherent to FM tasks, can result in FM personnel bypassing the retrieval of applicable information, exacerbating the likelihood of work-related fatality, injury, or illness.

Recently, a significant push has been made to incorporate operations and maintenance information into BIM models or computer maintenance management systems (CMMS) in order to consolidate the information to improve efficiency in retrieving information. Through the use of BIM interoperability,

virtual databases, and add-ons such as COBie, an improvement in O&M storage and retrieval has been achieved. However, this information has not focused on the storage and retrieval of safety information, and although there may be a small percentage of applicable information overlap, safety related information often remains unorganized and uncategorized. Nevertheless, utilizing these existing systems for storage and retrieval of safety information remains a viable and promising avenue of research. As shown by Meadati & Irizarry (Meadati and Irizarry 2010), building information models can act as a single, centralized database for knowledge storage and retrieval. The use of interoperability, virtual databases, and COBie are explored in much greater detail in subsequent chapters.

The following example presents a typical FRM task that a worker may encounter at a large utility or industrial plant. This example is intended to present the applicable safety information required for the activity and where that information is typically stored.

Project Example

A facility management worker receives an annual maintenance request to assess a Motor Control Center (MCC). An MCC is an assembly of combination starters in a single enclosure that contains motor starters, fuse or circuit breakers, and a disconnect (Siemens Technical Education Program 2014). These are commonly found in commercial or industrial applications where a number of motors are present and the owner wishes to consolidate the motor controls into one housing.

In this scenario, the FM worker will need to review the design drawings/specifications, 3D model, and/or CMMS system to find information such as power source, components, disconnect location, and schematics. This will provide a "lay of the land" and allow the FM worker to prepare for the MCC prior to opening the cabinet. For information such as MCC maintenance protocol, safety precautions (such as arc flash), warranties, and manufacturer information, the worker will need to review the O&M Manual provided by the contractor/manufacturer. Information within the O&M manual will often incorporate operations as well as some equipment specific safety information. Finally, the worker must abide by the high voltage gear safety protocol established by their organization. This information is typically available in a number of safety manuals, meeting minutes, OSHA documents, or adopted safety literature. All of this information will need to be extracted in order to develop of a comprehensive safety protocol that must be enacted by the FM worker to maintain a safe working environment.

Although some of this information may be stored in a virtual database or 3D model, it is unlikely that comprehensive, job specific safety related information would be available. By identifying and consolidating

the safety information relevant to the FRM task, the convenience in accessing and obtaining comprehensive safety protocol for the MCC is greatly improved. Minimizing the FM worker's inconvenience and providing a singular point for interaction would result in a greater likelihood of reference and safety protocol execution.

1.4. Statement of Problem

The following statements represent the problems that this research addresses.

Problem No. 1: Applicable project related safety information is often available at the handover stage from construction to facility management, but is not appropriately identified for facility management tasks. The information that would provide relevant safety data for a specific work activity is often uncategorized and therefore is left at the discretion of the worker whether or not the information should be utilized for a given task.

Problem No. 2: Fragmentation of applicable safety information within multiple project documents (O&M manuals, plans, specs, SDS, etc.), incomplete virtual databases, and/or multiple file formats creates inconvenience in obtaining comprehensive information, reducing the likelihood of reference by FM staff. This has been shown to impact hazard mitigation and increase the probability of work related fatalities, injuries, and illnesses.

1.5. Research Goal and Objectives

The goal of this research is to mitigate the fragmentation and timing inefficiencies within safety related information retrieval by developing a BIM-based framework to categorize, standardize, consolidate, and add logic to asset specific safety information. This is executed by establishing what safety information is important to FRM tasks, how the data is transferred, and how logic can be added to the safety data in order to efficiently present the information. By leveraging much of the work executed to date in the Building Information Modeling-Facility Management (BIM-FM) field, established and tested methods of data storage and transference can be utilized in order to develop a BIM-based framework.

By organizing the applicable safety data, patterns or commonalities are exposed. These patterns of data allow for the development of a set of inputs (known as "codes" in qualitative research) that can be associated with specific work activities that are relevant to the three safety hazards that this research is exploring. Using a Six Sigma Methodology to collect and analyze the data and validation methods using industry professionals, this study maintains quality and rigor commensurate with high level research.

Once the safety data is identified, the information can be placed into the framework. The structured inputs and associated values are placed into a comprehensive Navisworks model through a data transference mechanism. Through the use of existing software, the safety data can interact with a Data Retrieval and Processing System (DRPS). The DRPS utilizes rules to deliver task specific safety protocols based on stored asset information (safety values) and user input responses. This interaction between the FM worker and the DRPS, is presented through a UML Class Diagram, a Sequence Diagram, and a Conceptual Graphical User Interface (GUI). Use of this framework prior to the execution of a work activity will increase the likelihood of obtaining comprehensive safety information efficiently, better preparing the FM worker for the impending task. This will aid in the development of a safety plan that is specific to the equipment requiring maintenance or repair. The attainment of this goal will be carried out by the execution of the following objectives:

Objective No. 1 – Define, categorize, and standardize asset specific safety information applicable to falls, contact with / struck by, and harmful environments & substances.

The research uses qualitative coding to categorize safety information and applicable attributes within the three safety categories this research addresses. This is executed to develop a safety inputs and associated values as shown in *Figure 4*. To complete this objective and to mitigate the issue identified in *Problem Statement No. 1,* the following design is utilized:

- Develop a comprehensive list of safety inputs classified within the scope of this research
    - o A thorough review of safety documentation, NIOSH FACE reports, and interviews (Data Collection) are utilized in order to obtain a comprehensive list of safety related properties (inputs and values) relevant to FM workers.
    - o Data validation interviews are utilized to validate the safety related properties with industry experts.
- Organize, categorize, and standardize safety related information.
    - o Once identified, the safety related information is organized and categorized using spreadsheets & mind-mapping.
    - o Organized and categorized information allows for the development of an approach to standardize asset specific safety properties that can be input into a comprehensive BIM Model. Defining these properties and identifying which contract entity is responsible for supplying the values for each property allows for the applicable safety related information to be input into the system.
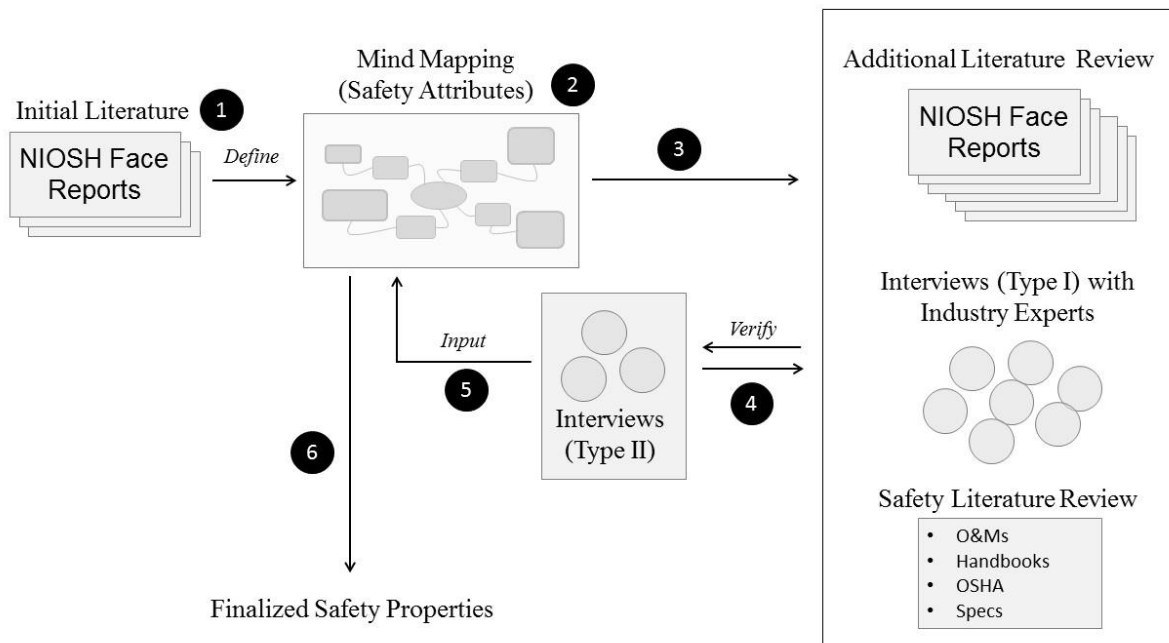
Figure 4: Safety Schema Development Methodology

The initial literature review of the NIOSH FACE Reports validates that safety information can be coded and placed into a mind map (2). Upon verification, an additional literature review (3), utilizing FACE reports, interviews (data collection), and safety literature takes place to obtain a more comprehensive review of the safety attributes and values associated with the categories this research is addressing. (4) At this point a second round of interviews (data validation) take place to validate the information gathered from the FACE reports, interviews (data collection) and safety literature. Once validated, the safety related information is organized and categorized using spreadsheets & mind-mapping (5) and produce finalized, coded, safety properties (6).

Objective No. 2 – Present a data path through defined transfer mechanisms in order to get safety information, in various formats, from design/construction to FM personnel into a singular repository.

- Categorized safety attributes and values are processed through various mechanisms, based on the applicable contract entities' existing infrastructure. The relevant safety information may come in the form of interoperable models, non-compatible models, documents, and other formats.
- In order to place all of this information into a comprehensive model, a number of IT Tools for data management and model integration are utilized.

- Once comprehensive relevant safety information is available within the BIM model, the information is available to interact with the developed Data Retrieval and Processing System (DRPS).

Objective No. 3 – Develop a data retrieval and processing system (DRPS) and conceptual graphical user interface (GUI), presented through graphics, to represent the interface between FM worker and DRPS.

- A data retrieval and processing system (DRPS) is used to add logic and guide the information exchange in order to provide applicable and necessary information to FM staff in a timely manner. For this research, structural and behavioral diagraming is utilized in the form of UML Class Diagrams and Sequence diagrams to capture the details of the static classes and relationships between the classes. The DRPS uses test cases in order to validate the functionality of the developed Class and Sequence diagrams.
- Through Java Eclipse, develop graphics for visual presentation of the conceptual GUI.
- Utilize the GUI in correlation with the Sequence diagrams to present a Proof of Concept.

Objective No. 3 is executed to mitigate the issues identified in *Problem Statement No. 2.*

Objective No. 4 – Validation

- Use professionals in the field of facility management to validate safety properties, data categorization, and framework through a cognitive walkthrough.

1.6. Research Assumptions and Limitations

The following section presents the assumptions and limitations made within the scope of this research.

Assumption No. 1 – Organizations wishing to utilize this data framework will have the appropriate infrastructure to run building information models.

To utilize the framework presented in this research, a facility management department must have the expertise, hardware, and software to access the building information model. This research assumes that any user implementing the framework presented herein will have these capabilities. If these capabilities are not readily available, additional infrastructure setup will be required by the implementing entity.

Assumption No. 2 – Users interacting with the system have the knowledge of BIM software and application.

Much of the system architecture of this research is built around the premise of BIM-FM, the use of a building information model during the facilities management phase. Users interacting with the DRPS will need to be comfortable working with data loaded graphical models.

Limitation No. 1 – This research will not address all possible hazards that facility management staff encounter.

This research will focus on the development of safety protocols for three of the major safety categories. These categories are as follows:

- Falls – Injuries and fatalities resulting from falls to lower levels.
- Struck-by/contact-with – Injuries and fatalities resulting from being hit with or forced against an item or equipment causing a crushing or slicing. This incident type is often related to automated equipment systems.
- Exposure to harmful substances/environments – Injuries and fatalities resulting from an environment that contains hazardous chemicals, toxic air, a lack of oxygen, or electrified equipment or surroundings. This category will focus mainly on confined spaces, electrified equipment, and hazardous environments.

Other types of accidents will not be addressed within this research. The selection of these three hazard types is explained in greater detail in *Section 2.2.1.1 Research Defined Hazard Types.*

Limitation No. 2 – The role of human interaction and safety culture in worker safety will not be addressed in detail.

This research recognizes the importance of the human interaction within safety scenarios, but will not address this aspect. In addition, the impact that safety culture has on the implementation of safety protocol and the FM worker's desire to enact the appropriate steps to mitigate risk are not addressed.

1.7. Proposed Framework and Research Contributions

Figure 5 presents the complete framework for the research. Throughout the lifecycle of the project, relevant safety inputs are given values by the various contract entities responsible for those assets from what would otherwise be fragmented safety information. Through various data transfer mechanisms, based on the type and format of the safety submissions, the relevant safety information is placed into a data storage repository. Utilizing process flows and existing IT tools for data management, such as software interoperability, Selection Inspector, and DataTools, the correct information can be stored in a similar format. In addition,

relevant safety information provided by the owner of the facility can be input into the system to meet organization specific requirements.

In order to retrieve task specific safety information, the user will launch the DRPS and select the asset requiring maintenance. Based on the values already in place for that particular asset, two background activities will take place. First, relevant safety applicable information will be sent to the end user interface for finalized safety protocol reference. Second, the DRPS will identify the need to ask the user a series of short questions in order to develop a task specific protocol based on the asset being serviced, environment, and circumstance. Utilizing a question based system urges the worker to proactively consider the safety plan prior to the execution of the task, similar to the tactics used in inquiry-based learning. Based on the asset selected and the responses by the user, a safety protocol output will be delivered to the FM worker.
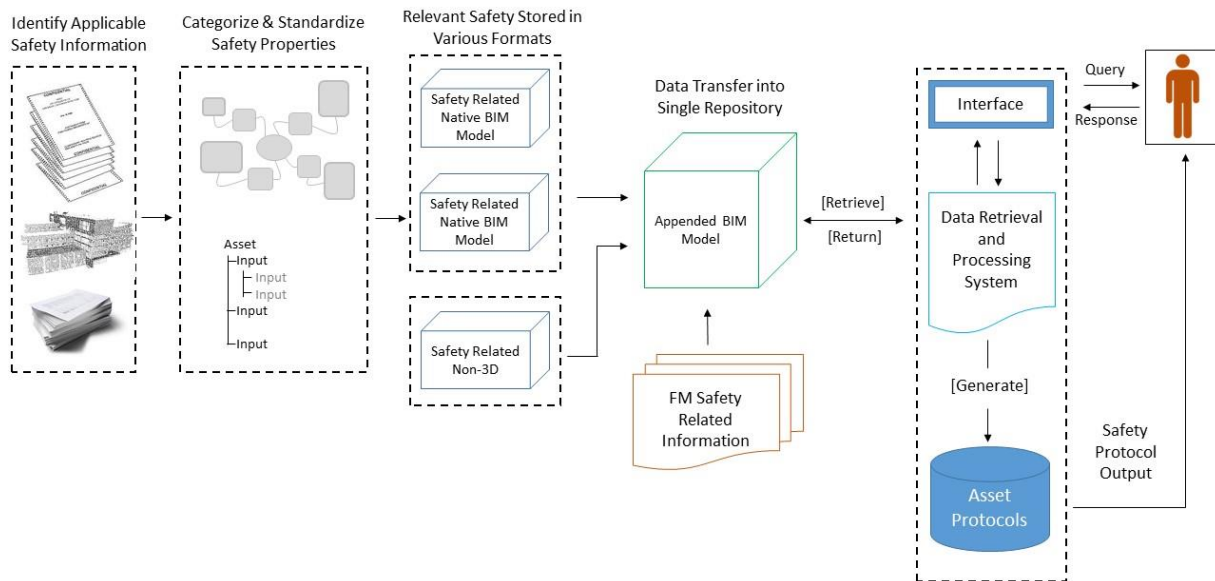
Figure 5: Proposed Framework

The proposed framework attempts to support safety during the facility management phase through two research contributions. These contributions are as follows:

- Develop comprehensive safety information in an effort to mitigate incidents in falls, contact with/struck by, and harmful environments & substances.
- Developed an approach to identifying asset group specific safety properties.

2. LITERATURE REVIEW

This chapter utilizes a literature review and gap analysis to identify current market trends and available technologies to support the current need for facilitating necessary information to perform facility management operations in a safer environment. In addition, a new method for facility management workers to interface with applicable safety protocol is proposed.

By exploring the topics of safety during facility management, the use of BIM for facility management, and the use of BIM for safety, a gap was identified in the form of the incorporation of BIM for safety during facility management as shown in *Figure 6*. These detailed research concepts were developed from three core concepts of facility management, safety management and building information modeling. A thorough understanding of the core concepts and sub-concepts of this research is necessary to identify the current processes utilized during facility management activities.
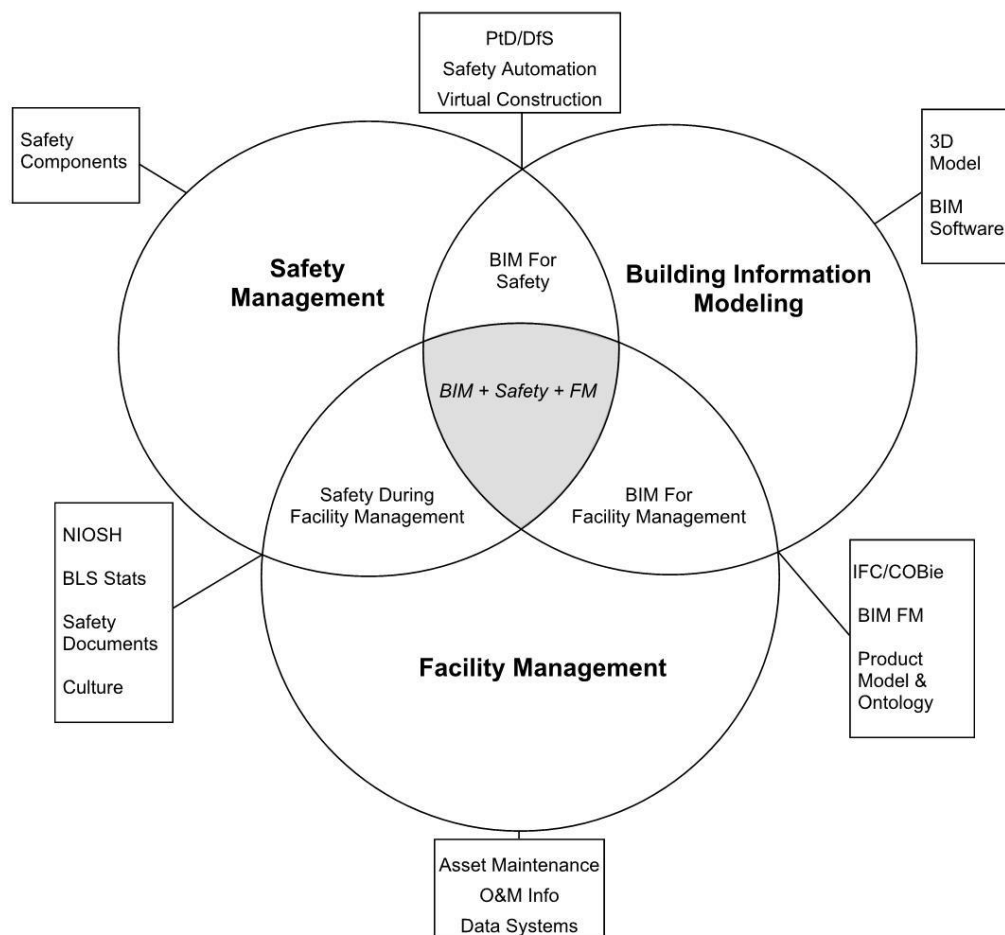
Figure 6: Literature Analysis Venn Diagram

In order to obtain a detailed understanding of current trends and research, this literature review utilized online resources such as OSHA, facility management, computer engineering, government websites, and peer-reviewed journal articles on the various topics. Additionally, discussions with industry experts were executed to provide a general understanding of topics. *Table 1* presents the resources utilized in each section of the literature review. The study will critically analyze the three areas stated and then comprehensively review and analyze the intersection of these three areas.

Table 1: Literature Review Resources by Category and Resource Type

Safety During Facilities Management	BIM for Facility Management	BIM for Safety
Online Resources (14)	Online Resources (5)	Online Resources (3)
Journal Articles (6)	Journal Articles (21), Book	Journal Articles (22)
Industry Expert Discussions (4) *Included: Engineering Firm, Major Utility Owner, University FM Staff, Facility Safety Expert*	Industry Expert Discussions (4) *Included: BIM Software Developer/User, BIM FM Consultants (3)*	Industry Expert Discussions (111th Congress of the United States of America) *Included: Professor (Safety Expert)*

Exploration of safety during facility management, the use of BIM for facility management, and the use of BIM for safety provided a comprehensive understanding of current market trends and research. A comprehensive, critical analysis of these areas as individual sections, allowed the research to identify overlap, eventually exposing a research potential. The proposed research framework will address this potential and present a solution to fragmentation and safety concerns within FM by incorporating BIM + Facility Management + Safety. *Figure 6* graphically presents the literature review approach that this study utilized to identify the research potential. Utilizing the information obtained through existing literature and current market trends aids in the development of the applicable safety protocols and proposed research framework.

2.1. Facility Management

Facility management is a profession that encompasses multiple disciplines such as electrical, mechanical and plumbing, to ensure the functionality of the built environment by integrating people, place, process and technology (International Facility Management Association 2013). Facilities management can be executed through in-house staff or by a third-party contract (FacilitiesNet 2014). The caretaking of a building is crucial to maximizing the service life of the building and equipment; however, this optimization does not come without a price. After payroll, facility management costs are typically the greatest administrative expense to an organization (Cotts et al. 2010). Failure to appropriately maintain a facility can adversely

impact the performance of an organization through equipment failure, the health of the organization's staff, and the safety of the building occupants. Conversely, a well maintained facility can enhance an organization's performance by contributing to the optimization of the working and business environment (Alsyouf 2007; Atkin and Brooks 2000; Roelofsen 2002).

The facility management department in any given organization may have many roles. From asset evaluation to design and construction consultation, the FM department needs to be aware of the organization's current assets and any planned additions, renovations, or new construction. In most cases, the largest role of the FM department is operations and maintenance (Cotts et al. 2010), usually identified simply as O&M. O&M is defined as "the activities related to the performance or routine, preventative, predictive, scheduled, and unscheduled actions aimed at preventing equipment failure or decline with the goal of increasing efficiency, reliability, and safety" (Environmental Protection Agency 2013). There are two types of O&M activities, *planned* and *unplanned*. Planned activities are defined as, "programmed, preventative and cyclical," while unplanned activities are "reactive" (Booty 2009). Examples of planned and unplanned O&M activities are identified in ***Table 2:***

Table 2: Planned vs. Unplanned O&M Activity Examples

Planned O&M Activity (Preventative)	Unplanned O&M Activity (Reactive)
Air conditioning unit filter change	Air conditioning condenser leak repair
Millivolt drop test at circuit breaker	Replacement of corroded contacts
Water heater tank flush	Replacement of pressure relief valves

Regardless of whether an O&M activity is planned or unplanned, the facility management staff is responsible for the caretaking of the facility. These individuals are highly skilled in a number of crafts that allow for versatility in maintenance scope. According to the Bureau of Labor Statistics (2013c) the field of facility management employed 1,230,270 people in 2012. Projections for this profession show a 9% growth through the year 2022 (Bureau of Labor Statistics 2014b). As the profession continues to grow and the complexity of buildings continues to increase, construction technology like BIM can provide benefit to the lifecycle of a facility and the safety of the staff (Teicholz 2013).

2.1.1. Facility Management Data Systems

To aid FM departments in maintaining and tracking assets, issuing work orders, and executing a number of other FM functions, software is available to track these data systems. Facility management and operations staff work with a variety of tools ranging from manual paper and spreadsheets, to more advanced computer based systems including Computerized Maintenance Management Systems (CMMS's), Computer-Aided Facility Management (TabsCAFM) tools, and Building Management Systems (BMS) (Parsanezhad and Dimyadi 2014).

Computerized Maintenance Management Systems (CMMS) are utilized by facilities maintenance organizations to record, manage and communicate their day-to-day operations (Sapp 2015). CMMS can be deployed for asset management, inventory control, generation of service requests, managing work orders of different types, and tracking the resources (time and costs) of services and materials used to complete work orders (Parsanezhad and Dimyadi 2014; Teicholz 2013). FAMIS (by Accruent), IBM Maximo, Corrigo, WebTMA (by TMA Systems), and AiM Maintenance Management (by AssetWorks), Vizelia, Ryhti and Rambyg are some examples of CMMS's (Mitchell and Schevers 2005; Parsanezhad and Dimyadi 2014). Many of these systems supports integration of BIM and IFC.

Computer-Aided Facility Management systems integrates a Computer-Aided Design (CAD) graphics module and a relational database software to provide various Facility Management capabilities (Sapp 2015) including space management tools (e.g. administering room numbers, departments, usable heights, room areas etc.). CAFM systems also provide means to collect data from a variety of sources through technology interfaces to other systems (such as CMMS) or human transfer processes. Many CAFM systems are web-based. FM:Interact (by FM:Systems), Archibus, and AiM Space and Facilities Management (by AssetWorks) are some examples (Parsanezhad and Dimyadi 2014; Teicholz 2013).

Building Automation Systems (BAS) are centralized, interlinked, networks of hardware and software, which monitor and control the facility environment to ensure the operational performance of the facility as well as the comfort and safety of building occupants (KMIC Controls Inc. 2015). Most of the automation system is behind the scenes as hardware devices mounted to equipment or hidden underfloor or in the ceiling. Some personalized control can be made available through thermostat-like devices. From a central management perspective, the BAS resides as software on an operator's computer or is available as a web page.

Even with the wide variety of software applications available to service facilities management needs, there is no single application that would encompass the diversity of all FM requirements (Sabol 2008).

2.2. Safety Management

The Federal Aviation Administration (2010) defines safety management as a, "formal, top-down business approach to managing safety risk, which includes a systemic approach to managing safety, including the necessary organizational structures, accountabilities, policies and procedures." The FAA recognizes four components to safety management (Federal Aviation Administration 2009):

- Safety Policy
- Safety Assurance
- Safety Risk Management
- Safety Promotion

Each of these components is described in greater detail in *Figure 7.* The example presented by the FAA is an exemplar model for occupational safety, including safety during facility management.
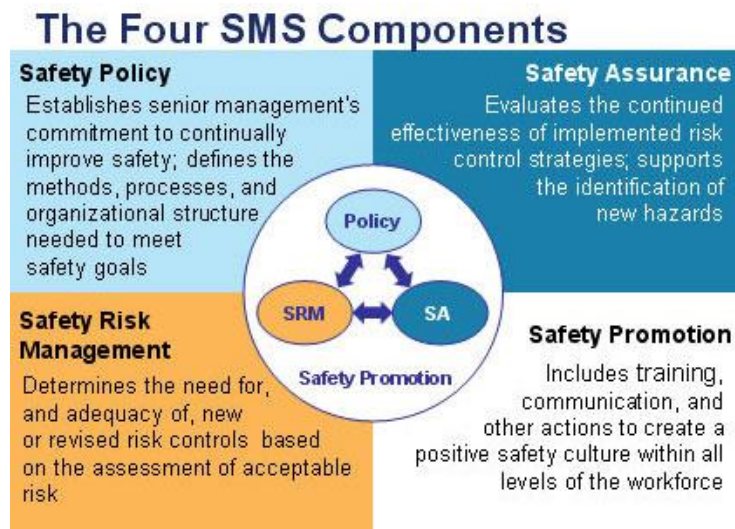
Figure 7: The Four Components of Safety Management (Federal Aviation Administration 2009)

2.2.1. Safety During Facility Management

This section addresses the current market trends and factors that are applicable to safety during facility management. Review of literature developed by large public and private entities and a governing safety

body (OSHA), presents a snapshot of the industry as it stands today. Obtaining an understanding of the approach being utilized by FM staff provides an insight into the factors responsible for the high injury and illness rates and increasing fatality rates (***Figure 8)*** present within facility management.
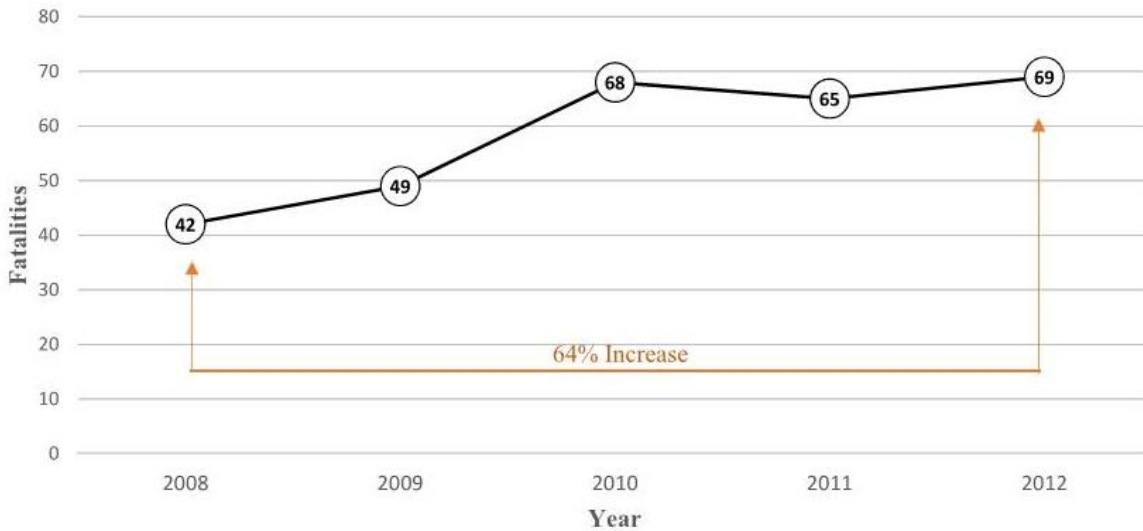
Figure 8: FM Fatalities by Year 2008-2012 (Bureau of Labor Statistics 2009a; 2010a; 2011a; 2012a)

For facility management staff, a thorough understanding of potential health risks that may be encountered during a work activity and the safety protocol utilized to mitigate the risks is of paramount importance. To remain proactive, many organizations maintain injury and illness prevention programs to reduce occupational injuries, illnesses, and fatalities (Occupational Safety and Health Administration 2013). These documents, although good for general safety information, are not tailored to specific work activities that a facility management worker would encounter on a daily basis. Legally, an organization is required to, "satisfy the ever-increasing number of federal, state, and local statutes relating to institutional health, safety, and the environment" (The University of Vermont Risk Management Group and Sarah Forbes Creative 2004). To comply with these requirements, many organizations develop risk management or safety handbooks specifically for the facility management department. These handbooks are developed to provide general safety guidelines for facility management staff including information on forklifts, personal protective equipment, rigging, scaffolding, and the like (e.g., Creighton University Facilities Management 2010).

In addition to safety handbooks and prevention programs, many facility management departments will hold, daily, weekly, or monthly safety meetings to discuss safety concerns, incidents, accidents and information on safety topics (University of Maryland Facilities Management 2012). Similar to safety handbooks, these meetings are an effective method for conveying general safety topics or reactively discussing an incident, but are often executed in a lecture format that has been shown to be less effective than an active learning approach. Safety meetings, also known as "toolbox talks" or "safety talks," typically present OSHA safety instruction, jobsite hazard training and general safety awareness for items like ladder safety, eye protection, and working at elevation (Duke Facilities Management 2014; Facilities and Services 2014).

To address specific work activities, some organizations have developed checklists that are reviewed prior to the initiation of an FM task (City of DuPont 2010). Checklists can be an effective tool if utilized correctly; however, there are a few inherent issues with relying solely on safety checklists. *Table 3* evaluates the pros and cons of utilizing safety checklists.

Table 3: Pros and Cons of Safety Checklists – Adapted from (Toups 2004)

Pros of Safety Checklists	Cons of Safety Checklists
Simple form of hazard analysis	May be irrelevant for complex equipment
Easy to use	Limited to expertise of its author(s)
Quick results, allows work to get underway	Hazard identification is subjective

Safety checklists can be a valuable tool, but as a standalone document rarely include enough information to fully encompass the dangers associated with specific job activities (Toups 2004). Regardless of the work activity a facility management worker is executing, the individual should have a working knowledge of the organizational, departmental, and individual safety requirements identified by that worker's company.

In addition to documentation, facility management departments typically require new and existing employees to attend training seminars. Training is an essential part of implementing accident prevention and gives a strong foundation for general safety processes and requirements (City of DuPont 2010). Training may be required to comply with federal, state or local law. Federally, the Occupational Safety and Health Act of 1970 was developed, "to assure safe and healthful working conditions for working men and women" (Occupational Safety and Health Administration 2004). Although the Health Act of 1970 does not specifically require employers to instruct or train employees, Section 5(a)(2) does require each employer to, "comply with occupational safety and health standards promulgated under this Act." A review of

individual safety and health standards yields more than 100 Acts that do contain training requirements (Occupational Safety and Health Administration 1998).

Recently, the United States Government passed the "Federal Buildings Personnel Training Act of 2010." This act requires personnel performing building operations and maintenance in federal buildings to complete comprehensive training and be able to demonstrate "competency relating to building operations and maintenance, energy management, sustainability, water efficiency, safety (including electrical safety), and building performance measures" (111th Congress of the United States of America 2010). This law was enacted to protect the citizens of the United States, whose tax money is utilized to operate federal buildings, by requiring minimum competencies of the individuals responsible for building performance (U.S. Department of Energy 2012). The safety portion of this bill protects the American taxpayer from worker's compensation claims and lawsuits.

2.2.1.1. *Research Defined Hazard Types*

As stated in *Section 1.6 Research Assumptions and Limitations*, this research is not intending to address all hazards present in facilities management. Instead, this research focuses on the primary dangers encountered by FM staff that could be mitigated by the developed framework. In order to obtain what dangers are most prevalent for FM staff, a breakdown of fatal and non-fatal data presented by the Bureau of Labor Statistics (2008-2012) is utilized.

The event that caused the fatal and non-fatal accidents is important in order to understand what type of incidents the framework should address. To this end, the framework is not intended to include incidences that have malice intent (i.e. assaults and violent acts) or transportation incidents. *Figure 9* presents the event information for fatal events and *Figure 10* for non-fatal incidents*.* In addition to the two figures presenting the number of fatal and non-fatal incidents.
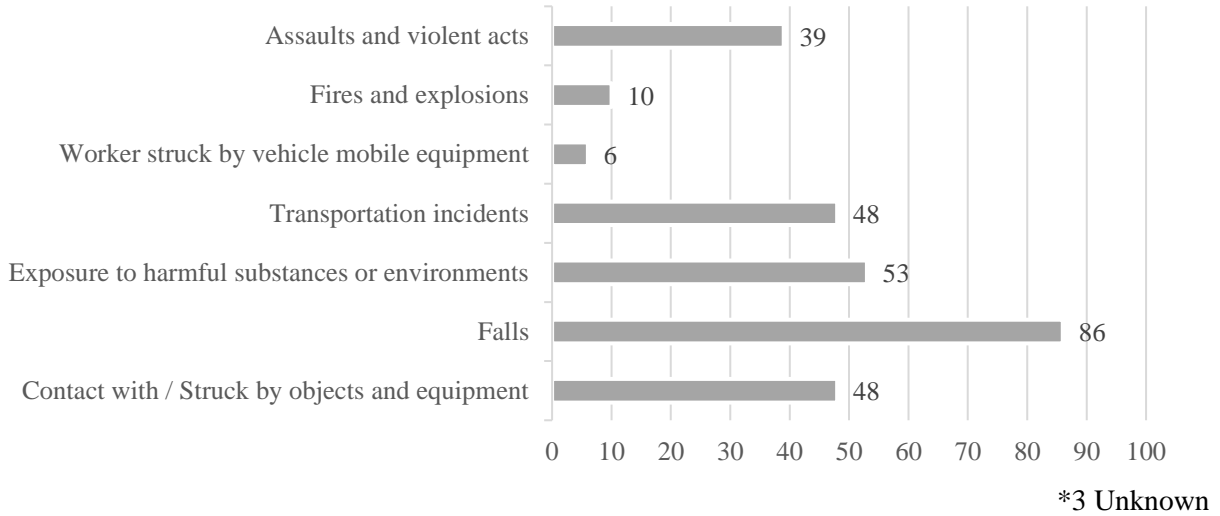
Figure 9: Event Information of FM Fatal Accidents 2008-2012

*80 Unknown
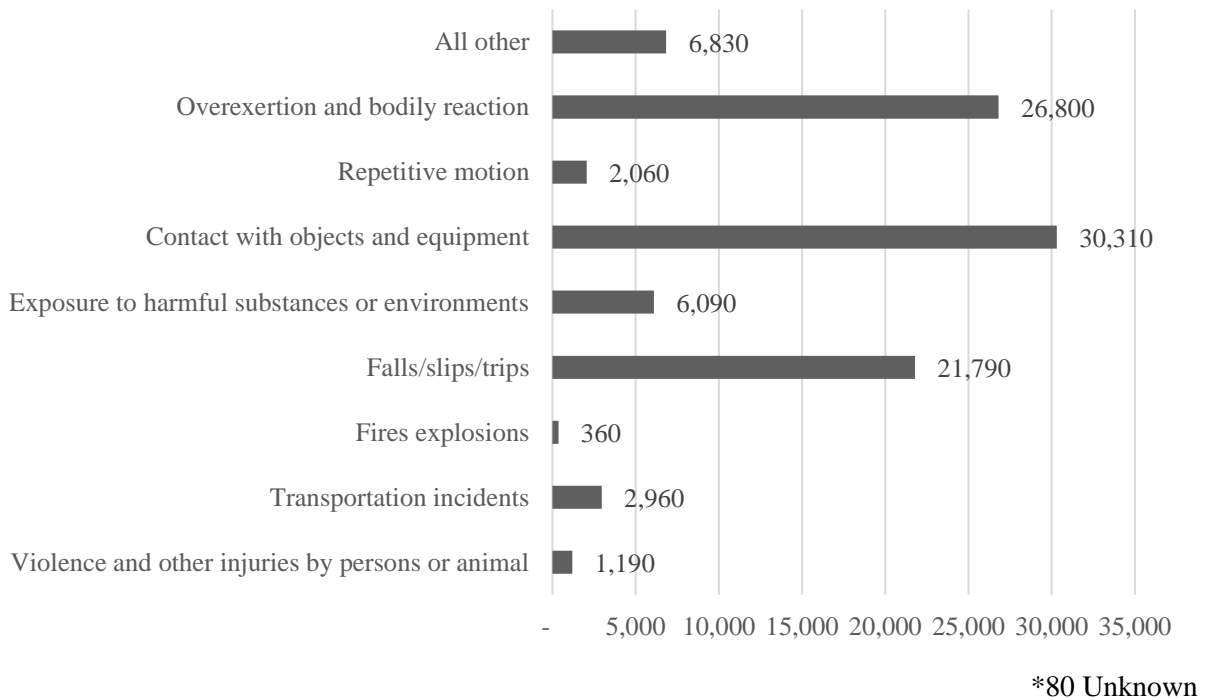
Figure 10: Event Information of FM Non-Fatal Accidents 2008-2012

Analysis of the event data shows that focusing the framework to address falls, exposure to harmful substances and environments (also referred to as hazardous environments and includes electrocution), and contact with / struck by is a relevant direction for the research as these three areas account for roughly 64.5% of all FM fatalities and 59.1% of all FM non-fatal incidents.

2.2.2. Safety Culture and Human Factors

Although this research is not intended to address safety culture and human factors, to obtain a comprehensive view of safety within the field of facility management, the perception of safety within an organization must be taken into account. The way facility management staff approaches the safety protocol of work activities will certainly depend on experience, training and available documentation, but will also depend on the worker's values, attitudes, and behavior towards health and safety (International Nuclear Safety Advisory Group 1992). Staff attitudes and behaviors towards safety, also known as *safety culture,* is often a direct reflection of the organization's culture (Crutchfield and Roughton 2014; Guldenmund 2000; Sorenson 2002). Organizations that take a proactive approach towards the safety culture are often more risk aware, informed, honest, adaptable and resilient (Leighton Contractors 2011).

In addition to the legal and moral obligations to prevent injury and preserve life to the best ability of the organization, an investment in safety culture yields financial benefit through reduced lost time and workers compensation expenses (Vredenburgh 2002). For every $1 invested on safety and health programs, a company will typically see a return of $4-$6 in lower healthcare costs, increased productivity and higher employee morale (Occupational Safety and Health Administration 2014).

The role that human decision making plays in the implementation of safety protocol cannot be understated. Human error, "a deviation from the performance of a specified or prescribed sequence of actions," accounts for 70-80% of operational accidents (Leveson 2004). This deviation can be due to any number of reasons, from an increase in system complexity to new hazard types. Similar to the role of safety culture, to minimize the amount of human error within a system, effective approaches will address the goals and the motives behind why a human approaches a solution, as well as how that information is presented.

2.3. Building Information Modeling

Building Information Modeling (BIM) is the process of creating a computer-generated model containing precise geometry and relevant data for support during construction, fabrication, procurement and facility lifecycle (Eastman et al. 2008). The use of BIM during the design and construction phase is widely accepted and studies have shown a number of benefits to implementing BIM early in a project (Bryde et al. 2013; Yan and Damian 2008). From reduction in design cycle time to a direct impact on construction cost, the use of BIM is slowly replacing the 2-D hand drafting and CAD applications that have been an industry standard for decades (Epstein 2012; Holness 2006). The term "building information modeling," can be dated back nearly twenty years, while the approaches and methodologies that are identifiable with BIM were presented nearly thirty-five years ago (Eastman et al. 2008). Although BIM has been around for two

decades, the functionality and features of the software have vastly improved as computer technology has evolved.

Today the marketplace boasts dozens of BIM software applications based on the scope the modeler requires. *Table 4* provides a short list of the software available in different categories. This table is not intended to be exhaustive, but to provide an idea of the variety of options available in today's marketplace.

Table 4: Available BIM Software by Category – Adapted from (Broquetas 2010)

Design	Sustainability	Construction
Autodesk Revit	Graphisoft EcoDesigner	Autodesk Navisworks
Graphisoft ArchiCAD	Autodesk EcoDesigner	Solibri Model Checker
Bentley MicroStation	Bentley Tas Simulator	Vico Office Suite
Tekla Structures	Autodesk Green Building Studio	Bentley ConstucSim

As designers, constructors, and owners continue to experience collaborative and financial benefits from BIM, as well as the ease of data sharing and the reduction in design time, it is likely that the industry will begin using BIM for design and construction as the industry standard in lieu of the exception. This shift has already begun with the development of a U.S. National BIM Standard, developed by the National Institute of Building Sciences buildingSMART alliance (2014).

2.3.1. BIM for Facility Management

This section explores how building information modeling has been utilized in facility management. Reviewing how current facilities are implementing BIM will provide an account of the abilities and limitations within these systems. Additionally, by studying research being executed presents advancements to the transference of data, the implementation of BIM systems, and solutions to specific industry issues.

With all the success that BIM has experienced during the design and construction phase, efforts to transfer information to the facility lifecycle phase is in its infancy. The utilization of BIM for facility management, also known as BIM FM, is a relatively new usage of building information modeling. Prior to the mid-1990's, to fully utilize the design and construction information during the facility management phase, the issue of data transference needed to resolved. With dozens of design and construction software programs

on the market, developed by a number of different vendors, interoperability between them was non-existent. In 1995, a consortium of twelve companies called the Industry Alliance for Interoperability (IAI) developed an object-based data model that utilized non-proprietary translators that could read the building information across a number of software platforms. The resulting data model was known as the Industry Foundation Classes or IFC (AECbytes 2004).

Today, IFC is published, maintained, and updated by the buildingSMART alliance. As a vendor-independent, open standard format, IFC is supported by roughly 150 software applications worldwide (buildingSMART International Ltd. 2014; Teicholz 2013). The interoperability of the IFC format allows designers, contractors and owners to utilize different software through the many phases of the building lifecycle without losing data due to the proprietary nature of individual software. The IFC data model is highly complex, but maintains a simple user interface. Because most software applications support the IFC data model, extraction of data for transference is typically an export option. The same ease is available for users attempting to import an IFC data model. As long as the software supports the IFC model, the information and model can be brought in through the import or appending function of the software.

In December 2005, the National Building Information Model Standard (NBIMS) Development Team introduced a component to the standard known as the Construction Operations Building Information Exchange or COBie (East 2007). COBie was released to improve how information is captured during the design and construction phases, and then turned over to the owner for operations and maintenance. COBie utilizes the open data format provided by IFC to attempt to bridge the gap between design, construction, and O&M by mapping commonality within the FM process. By approaching FM activities with an open source, interoperable set of standardized attributes, users can then customize the data to suit their facility needs.

Utilizing IFC and COBie for interoperability has allowed project teams to transfer design and construction data to owners at the beginning of the facility management phase, the implementation of these processes remains an uncommon occurrence. As Lucas (2012) described, "the AEC (Architecture, Engineering, Construction) industry information exchange through the facility lifecycle is fragmented and the facility management phase of the lifecycle remains the most disconnected from the rest." A study conducted by the National Institute of Standards and Technology (NIST) states that, "An inordinate amount of time is spent locating and verifying specific facility and project information from previous activities" (Gallaher et al. 2004). Many of the issues related to the implementation of BIM for FM is due to the factors addressed in *Section 5.2.1 Data Handover Challenges.*

In today's market, owners, researchers, and software developers have all realized the issues related to data transference from the end of construction to the O&M lifecycle phase. Owners have attempted to mitigate the issues with data transference by developing BIM-FM requirements and writing detailed contracts, BIM oriented specifications, and issuing BIM Management Plans that provide project specific methods in order to deliver facility data in a format that the owner is able to utilize. Researchers such as Lucas (2012), Kiviniemi and Codinhoto (2014), Lin and Su (Lin and Su 2013), and others have attempted to synthesize and bridge the gap in data loss between the end of construction and the beginning of the FM phase in complex buildings. By utilizing data exchange frameworks, analysis, and modeling, researchers are pursuing a seamless interaction between construction and post-construction phases. Software developers such as Bentley Systems are developing intelligent models (i-models) to intake, organize, and present equipment and facility data from a number of varying software sources into a single model (Cleveland 2014). Middleware solutions, such as EcoDomus, act as a bridge between a BIM model or database and an application. These systems have shown promise for sizeable organizations but are relatively expensive (Parsanezhad and Dimyadi 2014). Cheaper alternatives, such as Navistools, Datatools, and iConstruct, are application developments that target a specific task, but are not comprehensive enough to service all data transference needs.

Although the systems and research being utilized are young and still problematic, studies of organizations that have successfully integrated BIM FM to some extent, often sizeable government organizations, have shown promising results for utilizing BIM throughout the facility lifecycle. One such study shows a Return on Investment (ROI) of about 64%, with a payback period of 1.56 years (Teicholz 2013). These savings are realized through the intelligent use of the data collected through the design and construction phase and the integration of BIM FM to make better and faster maintenance decisions based on the data.

As owners, researchers, designers, and developers continue to make strides in the use of BIM throughout the building lifecycle, emerging technologies could help support the complex and data-driven information required for FM (Teicholz 2013). Cloud computing, mobile computing, RFID/QR technologies, augmented reality, and sensor data could all be incorporated into BIM models to provide real-time information. Additionally, the continued research into semantic interoperability and the use of semantic tools (extended algorithms, weighing and ranking systems, etc.) and ontologies will provide greater knowledge management for construction personnel (See *Section 2.3.2. BIM/Product Model and Ontology* for examples.). A number of resources into current and future applications of O&M information and technologies are presented by Sapp (2015) in the Whole Building Design Guide.

2.3.2. BIM/Product Model

A product model uses an object-oriented data structure to formally classify information to support the exchange of data through a mechanism (Eastman 1999). The mechanism utilized within a product model is an ontology, a set of translations for how information behaves within a system (Gruber 1993; Lucas 2012). Ontologies are often developed to identify domain specific vocabulary, structure domain knowledge, and exchange information (Chandrasekaran et al. 1999). By executing an ontology within a product model, a conceptual schema or framework of data can be properly structured and stored.

The use of ontologies and product models within construction have often been used to synthesize the cause-consequence sequences that are prevalent within the construction industry (Shansolketabi 2013). Lucas (2012) utilized a product model and ontology to evaluate the data transference of facility management information within a healthcare environment. Implementation of the product model and ontology allowed for the development of process models that evaluated the systems failures in HVAC equipment. Turkaslan-Bulbul (2006) developed ontologies and a product model which provided computational support for a standardization of building commissioning procedures. The resultant product model standardized commissioning of air handling units and provided a data exchange framework for building commissioning information. Tsai et al. (2009) presented an ontology-based framework that syndicates building intelligence. The proposed framework provides a system that enriches BIM models with knowledge functions, enabling the system to automatically generate responses to facility issues. Park et al. (Park et al. 2012), developed a construction knowledge retrieval systems using semantic tools to enable construction specific knowledge management. Others, such as Venugopal et al. (2012) and Yang and Zhang (Yang and Zhang 2006), have utilized semantic interoperability and ontologies for model exchanges and the advancement of IFC.

In a few cases, researchers have evaluated safety using ontologies. Zhang et al. (2014) recently presented an ontology-based sematic modeling system to capture construction safety knowledge. The ontology utilizes construction based safety information, such as the Occupational Safety and Health Administration (OSHA) regulation 1926 and the Occupational Injury and Illness Classification Manual, in an effort to enable more effective inquiry into construction site safety knowledge. Shansolketabi (2013) evaluated safety within a facility management application by utilizing "chain of events" analysis to evaluate mechanical failures due to improper maintenance. Within the evaluation, an ontology was developed using cause-consequence chains to enable automatic generation of event sequences for a selected domain. The resultant cause-consequence model provided potential failures of a boiler system if proper maintenance was not executed.

2.3.3. The Use of BIM for Safety

The role of BIM in safety began in 1990 when Hinze and Wiegand (1992) surveyed 35 major U.S. design firms to evaluate their role in construction workers safety, subsequently laying the groundwork for the implementation of safety within BIM. During this time period, CAD was primarily used by designers during the design phase, therefore surveying major design firms in the United States was a natural starting point. The results showed that only a third of the respondents made any design decisions based on contractor's safety.

In 1997, in response to the studies performed by Hinze and Wiegand (1992), Gambatese et al. (1997) developed a computer program titled, "Design for Construction Safety Toolbox." The tool was intended to "assist designers in recognizing project-specific hazards and implementing the design suggestions into a project's design." This program was the first application of "Prevention through Design" (Prevention through Design: Design for Construction Safety 2014). Prevention through Design (PtD) is a concept of, "addressing occupational safety and health needs in the design process to prevent or minimize the work-related hazards and risks associated with the construction, manufacture, use, maintenance, and disposal of facilities, materials, and equipment" (The National Institute for Occupational Safety and Health (NIOSH) 2013). PtD in Europe and Australia, place the legal burden of safety on all parties involved in the project, not just the contractor as OSHA requires in the United States (Behm 2005; Gambatese et al. 2008; Hecker et al. 2005; Her Majesty Stationary Office 1994).

Gambatese et al. (2005) have shown that PtD can reduce the percentage of incidence that occur on a construction project; however, the majority of PtD tools are primarily text based stand-alone checklists that often do not incorporate BIM (Ku and Mills 2010). A good example of this is the CHAIR system (Construction Hazard Assessment Implication Review) developed by Workcover (2001). The CHAIR system relates design decisions directly to the facility management phase by using a series of "guidewords" to prompt the project team in identifying safety hazards. In particular, CHAIR 3 identifies guidewords for the maintenance and repair phase. This system was developed to address the UK's requirement for the project team to address construction safety as noted earlier.

Although PtD has been around for almost 20 years, the utilization of BIM applications for safety is a relatively new concept and the research in this field is in its infancy. Ku and Mills (2010) state that using BIM to better address safety considerations via hazard recognition and design optimization could "create a built environment that successfully integrates safer construction processes." *Table 5* identifies the

applicable research in the "BIM for Safety" field, including the examples provided above. The table is being utilized to organize the research into the following categories:

- Phase – The portion of the building lifecycle the research is addressing.
- Area of Research – The correlation between the three hazard categories that this research addresses (falls, contact with/struck by, and hazardous environments) and the research being presented in the table.
    - o Other - Denotes a non-specific categorization.
    - o All - Identifies research that addresses all three categories.
- BIM Technology – The modeling tools or techniques used in order to achieve the research objective.
    - o BIM Design – Requires additional design to implement safety feature (i.e. scaffolding, fencing, etc.)
    - o BIM 4D – Utilizes 4D technologies (3D model & Schedule)
    - o Rules Algorithm – Utilizes a rule based system to output safety information
    - o Virtual Reality – Uses VR to visualize a work environment or process
    - o Design for Safety – Technique uses to forecast safety hazards using a BIM model

BIM for Safety in this research only refers to safety to humans and does not address safety of materials (e.g. structural integrity) or life-safety systems (fire safety).

Table 5: BIM for Safety Research

Phase	Area of Research	BIM Technology	Summary	Title	Author
Design	All	Design for Safety	Survey identifying the designers role in construction safety	Role of Designers in Construction Worker Safety	Hinze and Wiegand (1992)
Design	All	Design for Safety	400+ design suggestions that alert a designer when a project-specific safety hazard is identified	Tool To Design For Construction Worker Safety	Gambatese et al. (1997)

Phase	Area of Research	BIM Technology	Summary	Title	Author
Construction	All	Virtual Reality	A database of safety processes is incorporated into a "virtually real project" to allow for a walkthrough to identify safety hazards and select accident prevention	Integration of virtually real construction model and design-for-safety process database	Hadikusumo and Rowlinson (2002)
Design	All	Design for Safety	A theoretical basis developed to provide a tool that architects, engineers, construction managers (CMs) and specialty contractors can use to estimate the time, cost, and worker safety impacts of specific design and construction process alternatives for their projects	The Link Between Design and Process: Dynamic Process Simulation Models of Construction Activities	Slaughter (2003)
Not Applicable	Other	Virtual Reality	Using virtual reality for hazard identification training in mining operations	Implementation and evaluation of a VR task-based training tool for conveyor belt safety training	Lucas and Thabet (2008)
Construction	Fall Hazards	BIM 4D	Uses 4D for site organization to promote safety against falls	BIM-based site layout and safety planning	Sulankivi et al. (2009)
Construction	All	BIM 4D / Rules Algorithm	A conceptual model that enables forecasting of safety risks in projects for different trades. Uses a knowledge base of construction activities and probabilities of loss-of-control events, coupled with a project's construction plan and a digital building model, to forecast risk levels for work teams	'CHASTE': construction hazard assessment with spatial and temporal exposure	Rozenfeld et al. (2009)

Phase	Area of Research	BIM Technology	Summary	Title	Author
Construction	Fall Hazards	BIM 4D / Rules Algorithm	A rule based system that analyzes design information to automatically detect working-at-height hazards	An integrated safety management with construction management using 4D CAD mode	Benjaoran and Bhokha (2010)
Not Applicable	Other	BIM Design	Uses computer image generation for job simulation (CIGJS) to review potential safety hazards in occupational settings. This is not specifically geared towards construction, but could be utilized as such	Computer image generation for job simulation: An effective approach to occupational Risk Analysis	Patucco et al. (2010)
Construction	Falls & Hazardous Environments	BIM 4D / Rules Algorithm	1) Uses safety codes to automatically generate Dynamic Virtual Fences (DVF) for collision prevention & fall protection 2) Uses Real-Time Location Systems (RTLS) for worker tracking to provide warnings when approaching hazardous areas	Automatic Generation of Dynamic Virtual Fences As Part of BIM-Based Prevention Program for Construction Safety	Hammad et al. (2012)
Design and Construction	All	Virtual Reality / BIM 4D	Explores relationships between construction safety and digital design practices with the aim of fostering and directing further research. It surveys state-of-the-art research on databases, virtual reality, geographic information systems, 4D CAD, building information modeling and sensing technologies	Construction safety and digital design: A review	Zhou et al. (2012)

Phase	Area of Research	BIM Technology	Summary	Title	Author
Construction	Fall Hazards	Rules Algorithm / BIM 4D	Fall hazard safety issues unknowingly built into a construction schedule can be identified by utilizing Automated Safety Checking in a 4D simulation application	Utilization of BIM-based Automated Safety Checking in Construction Planning	Sulankivi et al. (2013)
Design	Fall Hazards	BIM Design / Rules Algorithm	Algorithms that automatically analyze a building model to detect safety hazards and suggest preventive measures to users are developed for different cases involving fall related hazards	Building Information Modeling (BIM) and Safety: Automatic Safety Checking of Construction Models and Schedules	Zhang et al. (2013)
Construction	All	Rules Algorithm	Utilizes construction based safety information, such as the Occupational Safety and Health Administration (OSHA) regulation 1926 and the Occupational Injury and Illness Classification Manual, in an effort to enable more effective inquiry into construction site safety knowledge through the use of an ontology	Ontology-Based Semantic Modeling of Safety Management Knowledge	Zhang et al. (Zhang et al. 2014)
Construction	All	Rules Algorithm	Identifies focal points of occupational accidents as well as risks & hazards influencing the safety of construction workers. Determines the job hazards related to construction process. After linking to a 3D building model, the results are demonstrated with the commercial BIM software ceapoint desiteMD	Model-Based Construction Work Analysis Considering Process-Related Hazards	Melzner et al. (Melzner et al. 2013)

Phase	Area of Research	BIM Technology	Summary	Title	Author
Construction	Fall Hazards	BIM Design / BIM 4D	Investigated the effectiveness of BIM technologies in developing, communicating and implementing a construction site safety plan. Four-dimensional (4D) phasing simulations, 3D walk-throughs and 3D renderings were utilized for identifying hazards and communicating safety management plan to the workers	A BIM-based Approach for Communicating and Implementing a Construction Site Safety Plan	Azhar and Behringer (Azhar and Behringer 2013)

The following tables present the "Area of Research" and "BIM Technology" usage within *Table 5. Table 6* presents the categories identified under "Area of Research" and the ratio to the total percentage of each area, while *Table 7* does the same with "BIM Technology."

Table 6: Categorization of Area of Research and Percentage of Each Category

Area of Research	Percent of Literature
All (8)	50%
Falls Only (5)	31%
Other (2)	13%
Falls and Hazardous Environment	6%

Table 7: Categorization of BIM Technology and Percentage of Each Category

BIM Technology	Percent of Literature
BIM 4D (7)	30%
Rules Algorithm (7)	30%
BIM Design (3)	13%
Design for Safety (3)	13%
Virtual Reality (3)	13%

By mapping the "Area of Research" to the "BIM Technology," tools and techniques can be correlated to issues that this research is addressing. ***Figure 11*** presents this mapping in order to organize the findings so it can be utilized during the development of the proposed framework (see *Section 4*). Line weights indicate the frequency of correlations.
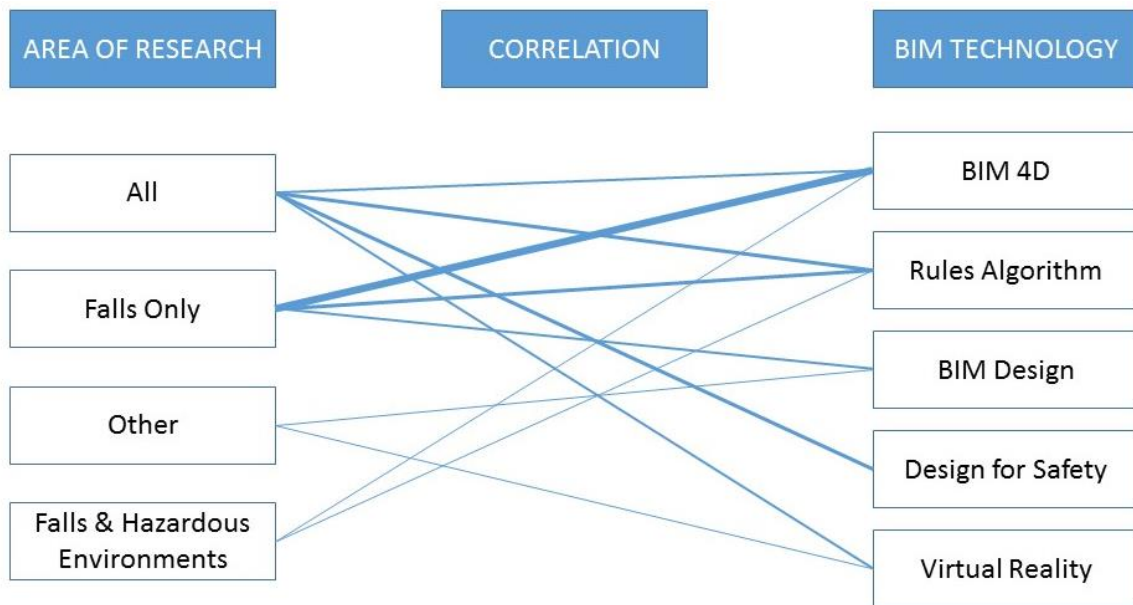
Figure 11: Correlation of "Area of Research" and "BIM Technology"

2.4. Analysis of Literature Review

As the FM industry continues to see incidence rates well over the national occupational average and an upward trend in fatalities, a fundamental shift in how safety information is disseminated and presented must take place. As the literature review has shown, a great deal of documentation has been produced in order to create a safe working environment for FM workers; however, this documentation only adds to the problem by creating even more sources of information requiring extensive reference prior to the start of an FM task.

The incorporation of BIM into facilities management has attempted to improve where the documentation is stored and how it is presented but is rarely utilized due to "handover issues." Additionally, this information is rarely safety oriented, but instead is more asset and O&M based. Research being done to integrate BIM and safety has shown promise; however, a substantial amount of this research has been geared towards a safe working environment during the construction phase. As a result of the analysis conducted on current trends and technologies, the following summarizes the current challenges faced in each of the three areas of investigation.

Bureau of Labor Statistics data has shown, the upward trend of accidents within the field would indicate that FM workers are not executing tasks utilizing the appropriate safety information. This could be due to any combination of factors, including availability of information, safety culture, time constraints, or expertise. By adding convenience in obtaining information and simplifying the interface with which that data is presented, the likelihood of reference, retrieval, and execution for the three hazard types this research is addressing will improve. This increased convenience will shorten the amount of time and effort an individual must spend in obtaining comprehensive safety information, expediting the reference timeframe and providing more time for the execution of the task. Additionally, simplifying the process should improve the worker's attitude toward referencing the safety information, thus positively shifting the culture.

Software advancements and research done in building information modeling in regards to facilities management has made immense steps within the last decade. The issues with data transference has been considered and continues to be addressed today. Although these systems are not seamless and the industry still experiences issues with data capture and transference, through advancements in IFC, COBie, i-models, middleware, and research, the flow of information at the completion of a construction project into the FM phase is more streamlined than ever before. To date, much of this data management has focused on the flow of O&M information, construction as-builts, and asset management, with very few cases focusing on the identification and subsequent transference of relevant safety information. By proactively establishing a protocol for safety, based on the equipment and environment present within the facility and structured within the BIM model, the information that is important to FM personnel can be obtained and presented independently in a BIM-based format, without the need to syphon through significant amounts of information.

Based on the information reviewed in the current market literature, analysis of the utilization of BIM for safety during the FM phase, shows none of the available literature reviewed has focused on the FM phase. However, analyses of the literature can help identify tools and techniques that could be expanded to consider

the FM phase. By identifying what tools/techniques are being utilized and how those tools/techniques correlate to the hazards that this research attempts to mitigate, parallels to the framework that this research is developing can be made and potentially implemented within the system.

As a result of the analysis conducted on current literature, the following *Table 8* summarizes the current challenges faced in each of the three areas of interest that the proposed framework attempts to address.

Table 8: Current Challenges This Research Attempts to Address

Safety During Facility Management	Information is often fragmented creating inconvenience in obtaining comprehensive safety related information.
BIM for Facility Management	Handover/Data transference issues are still prevalent.
	Handover information is rarely safety based.
BIM for Safety	Research is heavily focused on the design and construction phase.

3. RESEARCH METHODOLOGY

This research aims to support safety during the facility management phase by identifying safety relevant information applicable to facility management and delivering that data in a singular BIM-based framework. The methods used in order to execute the research goals is based on qualitative analysis through the theoretical lens of a Six Sigma methodological approach. Define-Measure-Analyze-Design-Verify (DMADV), is a popular phased analytical tool used for the development of processes, services, or products under the Six Sigma methodology, Design for Six Sigma (DFSS) (Rumane 2013). The framework focuses on the development of processes, services, or products through end-user interaction. This interaction can be expressed through qualitative processes (i.e. interviews, case studies, etc.) (Narayanasamy 2015), as is the case in this research. Logan et al. (2005) states,

"Design and new product development often involves qualitative goals and depends on advances in research and development yet to come to fruition… The Design for Six Sigma process is ideally suited to deal with both qualitative and quantitative aspects, and has the added advantage of a smooth transition into the product phase use of Six Sigma principles."

The DMADV framework is flexible enough to be utilized exclusively as a qualitative method or as a mixed methods framework, as presented by Mahasneh (2014). Although frequently implemented in the manufacturing and business worlds, the use of Six Sigma methodologies has been shown to be an effective approach in construction research (Banawi 2013; Koziolek and Derlukiewicz 2012; Lee and Su 2013; Mahasneh 2014; Paslawski 2013; Vilasini et al. 2014).

By structuring the research within the DMADV framework, the methods utilized for data collection, organization, and presentation can be anchored in a tested methodology for the deliverables developed within this research. As Six Sigma is primarily a tool for quality in the manufacturing of products, a correlation to the development of a framework can be extrapolated. By using the steps identified under DMADV, the research design and execution is continuously gearing the development of the framework towards the end user and the end user's needs. In this research, the end user is facility management staff and the end user's needs are the retrieval of safety related information efficiently. Combining the theoretical framework with the researcher's experience and existing literature provides a conceptual framework that, as described by Rossman and Rallis (2012), "underscores the interaction between the inductive (reasoning from the particular to more general statements to theory) and deductive (starting with theory and testing its applicability) processes of research." *Figure 12* provides a visual representation of how the DMADV

theoretical framework will be incorporated into this research. Details of the framework and the methods utilized to execute this methodology are provided in *Section 3.1.*
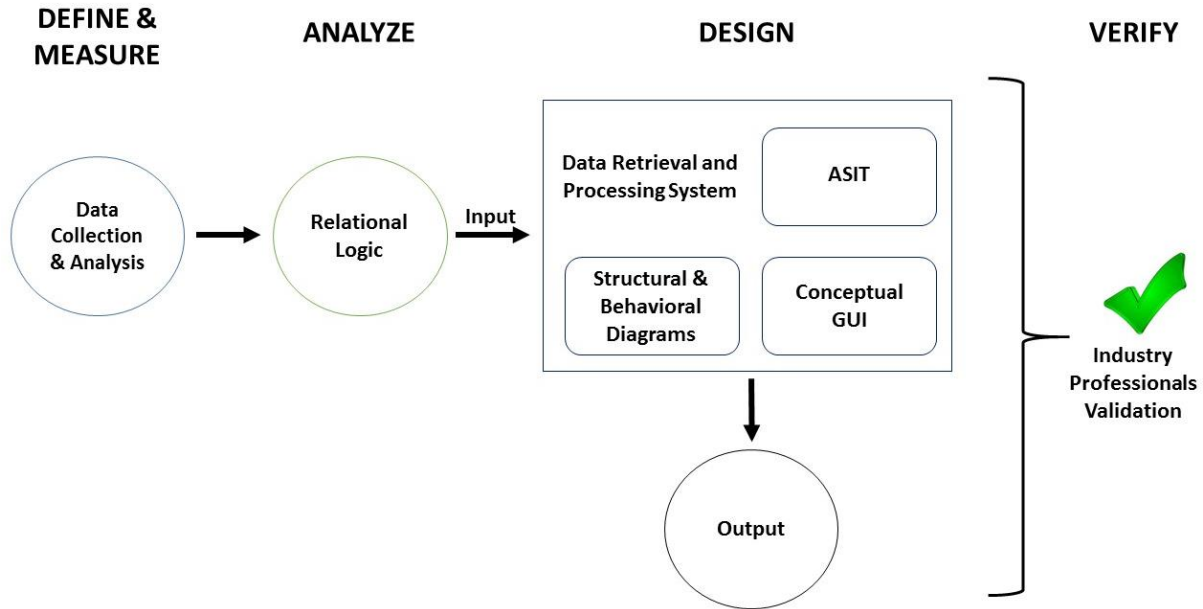
Figure 12: The DMADV Theoretical Framework in this Research

In this chapter, a detailed explanation is presented for the methods this research utilizes within the context of the Six Sigma methodology and the qualitative approach. *Section 3.1* provides background on the DMADV framework, presents the methods used to execute research, and presents the research methods within the DMADV theoretical framework, *Section 3.2* describes the role of the researcher for this study, and *Section 3.3* presents the research trustworthiness and ethical considerations.

3.1. Research Design

The following section details the DMADV theoretical framework, identifies the methods being utilized to mitigate the problem statements identified in this research, and describes how these methods are structured within the DMADV theoretical framework. This research utilizes qualitative analysis during data collection in the form of case study analysis, coding of safety related information, and interviews. Data collection is validated by a second round of interviews with industry professionals. The coded data is then organized through mind mapping, standardized through a developed tool, translated into Unified Modeling Language, and placed into a product model and sequence diagram. A conceptual graphical user interface (GUI) utilized in correlation with the diagrams, provides a proof of concept to the system functionality.

3.1.1. Theoretical Framework Background

The Six Sigma methodology was initially developed by Motorola in the mid 1980's to reduce defects in the manufacturing process (Tjahjono and Ball 2010). Initially, Six Sigma was heavily quantitatively based, with a singular goal of minimizing manufacturing defects to 4 Defects per Million (Logan 2005). Since that time, the use of this methodology has expanded into multiple industry sectors and is still being implemented in new sectors today. Additionally, the Six Sigma methodology, has expanded far beyond a single quantitative metric into mixed and qualitative methodologies. Six Sigma is most often utilized when improving the quality and organization of an existing process or product through the use of Define-Measure-Analyze-Improve-Control (DMAIC). This analytical process provides a systematic approach to the evaluation and continuous improvement to optimize an existing process or product (Koziolek and Derlukiewicz 2012; Sokovic et al. 2010). The DMAIC system has been shown to be an effective tool for existing process/products, but when a new process is to be developed, as is the case in this research, a different approach should be utilized.

Design for Six Sigma (DFSS) has become a worthy predecessor to DMAIC in the application of new process/product development under the Six Sigma methodology (Logan 2005). One of the most frequently reported methodologies for implementing DFSS is the use of the Define-Measure-Analyze-Design-Verify or DMADV (Sokovic et al. 2010). Similar to DMAIC, the DMADV system uses a systematic approach to develop products that have been verified through interaction with the end user. Each phase within the DMADV methodology has a specific task. These phases are defined in the context of this research in *Table 9*. A full description of the methods utilized in this research and how those methods are structured within the DMADV methodology is demonstrated in the *Section 3.1.3*.

Table 9: Definition of the DMADV Methodology in the Research Context

Phase	Definition
Define	Identification of the data and information for the stated goals.
Measure	Identification of "benchmark" and verification of data collected during the Define phase.
Analyze	Qualitative Analysis of the information gathered during the Define and Measure phases.
Design	Implementation of the knowledge gained through the Define, Measure, and Analyze phases.
Verify	A third party validation of the designed system.

3.1.2. Research Methods for Proposed Framework

The proposed BIM-based framework and stages are based on a qualitative analysis through the theoretical lens of a Six Sigma methodological approach. Define-Measure-Analyze-Design-Verify (DMADV), is a popular phased analytical tool used for the development of processes, services, or products under the Six Sigma methodology, Design for Six Sigma (DFSS) (Rumane 2013). The BIM-based framework focuses on the development of processes, services, or products through end-user interaction.

The DMADV theoretical framework is used to provide a structure for the methods of data collection and the development of the framework. *Figure 13* presents the research methods within the DMADV theoretical framework. The first column in *Figure 13* presents the DMADV phase, the second column defines the phase, developed from The Pennsylvania State University (2008), and the third column presents the research methods utilized within this research in the DMADV context.

PHASE	DEFINITION	RESEARCH METHODS
Phase I DEFINE	Identify the purpose and establish a clear definition of the process	FACE Reports Data Collection Interviews Safety Literature Spreadsheets & Mind Mapping Literature based discovery, data collection, and data categorization identify the safety related information that is applicable to the safe maintenance of a facility. This information conveys the need for a new process and defines the initial data required for the safety framework.
Phase II MEASURE	Identify user requirements and critical parameters that are critical to quality	Data Validation Interviews Type II Interviews serve to validate the information obtained during the Define phase and to benchmark the safety data obtained.
Phase III ANALYZE	Develop conceptual designs, evaluate, and select the best components	Define Rules and Protocol Knowledge Defining rules and relationships to add logic to the static safety related information obtained in the Define phase and validated in the Measure phase in order to develop standardized safety asset groups, process diagrams, and a conceptual user interface.
Phase IV DESIGN	Develop design	Structural & Behavioral Diagrams Tool Development Implements the safety rules and protocols through the Analyze phase through a data processing & rule based systems.
Phase V VERIFY	Validate the design is acceptable to the end user	Proof of Concept Test Cases Walk-through Supports the quality of the framework through test cases and expert validation.
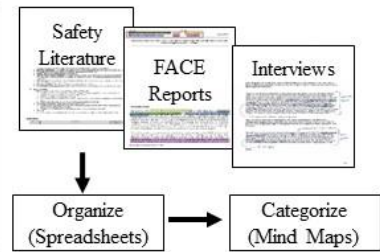
$$=IF(AND(X,Y))$$
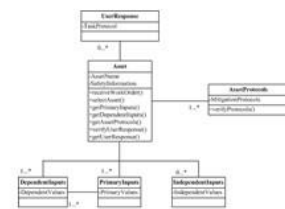
Figure 13: Research Methods within the DMADV Framework

Phase I: Define

Using Literature based discovery and data collection, the safety related data that is applicable to the safe maintenance of a facility is identified. In order to obtain safety data, case study analysis of FACE reports, semi-structured open-ended interviews (data collection), and safety related information, such as O&M Manuals, safety handbooks, OSHA handbooks, etc. are analyzed through qualitative coding. Analysis of this information provides safety data that is utilized to develop safety inputs. The safety data is first organized through Excel Spreadsheets in order to identify commonalities and then categorized using Mind Maps to present a hierarchy of the static information.

Phase II: Measure

Data Validation Interviews executed during the Measure phase serve to validate the information obtained during the Define phase. In this phase, the interviewee benchmarks the critical parameters and validates that the data obtained in the Define phase is comprehensive, accurate, and commensurate with industry standards.

Phase III: Analyze

Based on the safety inputs identified in the Define phase and validated through the Measure Phase, relational logic is developed using conditional constructs in order to further structure the safety inputs and begin to define the functionality of the BIM-based framework.

Phase IV: Design

Develop an approach to standardize asset specific safety properties and deliver the properties from its point of origin to the end user in a singular BIM-based repository. Develop a system to retrieve and process the safety properties in order to be presented to the end user within a conceptual graphical user interface (GUI).

Phase V: Verify

Supports the quality of the framework that this research develops. Utilizing a Proof of Concept model, test cases, and industry expert walk-throughs to verify the functionality of the developed safety inputs, ASIT, and DRPS. Items from the verify phase will be utilized in future research and further development of the framework.

3.1.3. Research Methods

This section presents the research methods being utilized within this research in order to execute the objectives stated in Section 1.5.

3.1.3.1.   *Data Collection and Organization – Objective No. 1*

Case Study Analysis is an intensive investigation of people, organizations/institutions, events, and occurrences, used to identify phenomena, themes, concepts, or principles from which a theory can be developed or practice improved (Fritz 2008). This research utilizes a modified paradigmatic explanatory multiple case study analysis in the evaluation of Fatality Assessment and Control Evaluation (FACE) reports to illustrate common patterns or themes (Yin 2003). The following bullet points will explain each modifier presented under the type of case study analysis being utilized:

- Modified – The case study analysis in this research analyzes the information that the FACE Reports are presenting in order to pull data points (or codes) from these reports.

- Paradigmatic – A type of case study analysis that uses careful selection of examples to reveal key elements of a phenomenon (Pavlich 2010). This research only uses cases regarding occupational injuries, illnesses, and fatalities to workers in the field of facility management as a result of falls, contact-with/struck-by, or exposure to harmful substances/environments.

- Explanatory – Case study analysis focused on the "how" and "why" a phenomena occurred (Yin 2003).

- Multiple – Research that utilizes more than one case study, is known as a "multiple." This research will utilize a number of FACE Reports to explore differences and similarities within and between cases (Baxter and Jack 2008; Yin 2003).

This research has identified case study analysis as the best method of data extraction from the FACE Reports for a number of reasons. These reasons are presented below:

- Detailed accounts of existing real-life events are available from a reliable source.

- Relevant behaviors cannot be manipulated.

- Direct observation is not viable as events cannot be safely recreated.

- Case study analysis will be combined with safety related documentation and interviews to create "triangulation" in order to develop converging lines of inquiry.

The FACE reports provide an understanding of "how" and "why" fatalities are occurring in the field of facilities management. This information is critical to the execution of *Objective No. 1*, by identifying FM applicable safety data and the subsequent use of that data to develop safety protocols. In order to achieve this objective, multiple case studies falling under the categories being investigated by this research will be reviewed in order to develop safety codes through qualitative coding. These codes are pieces of information, relevant to the "how" and "why" an accident occurred. Using thematic analysis to evaluate code

frequencies, co-occurrences, and relationships, the codes can be organized and categorized to support analytical generalizations (Guest et al. 2012; Robson 2011). The FACE Reports are coded by hand or within a .pdf markup software. Codes are placed into an Excel spreadsheet for organization, prior to being further organized utilizing mind mapping.

Each case study reviewed for this research set out to answer four questions. Under what circumstances did the accident occur? (2) Could the accident have been avoided? (3) What measures could have been taken to improve the safety? (4) Could these measures be applied to multiple situations?

Qualitative Coding will also be used as a source of information to develop safety codes from industry standard literature, such as, Operations and Maintenance Manuals, Safety Handbooks, OSHA handbooks, etc. Qualitative coding uses the, "analytical process of organizing raw data into themes that assist in interpreting the data" (Baralt 2012). For this research, qualitative data will be hand coded and placed into an Excel spreadsheet for organization, prior to being further organized utilizing mind mapping. Similar to the case study analysis and interviews, thematic analysis is utilized to find the relevant safety information needed to execute this study. Data collection from industry standard literature requires the use of constructivist theory. The data pulled from these documents is often uncategorized and therefore is at the discretion of the author of the data's importance. This information is later validated through Data Validation Interviews.

Semi-structured, open-ended interviews - Data Collection Interviews with experts in the field of facility management will aid in the compiling and categorization of applicable safety data. Similar to the other data collection methods, Data Collection Interviews are intended to provide codes through qualitative coding of transcripts and thematic analysis. These codes will then be incorporated into the framework, similar to the codes identified through the FACE Reports and safety literature. This research utilizes data saturation for the three hazard areas and therefore the number of participants required is unknown. Interviews are not be fully structured and appear more as a guided conversation rather than structured queries. This method allows for a more fluid/dynamic interview where a consistent line of inquiry is being pursued, however, the format provides an opportunity for follow-up questions and parallel lines of inquiry (Yin 2003). The sampling of interviewees will be purposive, by targeting a particular group of people based on the criteria of knowledge of facility management and safety applications. Participants in this study meet the following inclusion criteria:
- Facility management professional – This could include field staff or supervisory staff
- Over 18 years old

- Minimum 6 months working at current position – This is to avoid interviews with trainees or individuals not well versed in the field
- Able to speak and read English

The inclusion criteria this research utilizes was strategical situated to obtain qualitative data from FM experts. Gathering safety data from experts provides, in combination with the other data sources, a comprehensive list of safety inputs and protocols.

Semi-structured, open-ended interviews - Data Validation Interviews are used to validate the data compiled through the case study analysis, safety data, and Data Collection Interviews. Data Validation interviews utilize interviewees to validate data saturation and accuracy. Due to the nature of these interviews, the questions asked will be focused more on validation of collected data.

The interviews are audio taped and field notes are taken to allow for qualitative analysis. Interviews last between 60-90 minutes, face-to-face with the lead researcher, at a location identified at interviewee's discretion. If a face-to-face interview is not possible due to travel restrictions, a virtual meeting (i.e. FaceTime or Skype) is an acceptable alternative. Participants are identified by locating facilities that have staff that could meet the inclusion criteria, for example, contacting the administrative office or FM department directly at a water treatment facility, school, university, or factory. Once an FM supervisor is identified at the facility, a phone call will be made to verify the contact information with the supervisor, confirm compliance with inclusion criteria, and obtain an interest level of study participation. If the participant is interested in participating, a recruitment email will be sent outlining the details of the study, as well as other IRB required information. Snowballing, or allowing the selected participant to provide names of other potential participants, is utilized on a needed basis. Upon completion of the interview, participants are debriefed by describing the process of member checking (see *Section 3.3.2*) and are notified of the right to drop out of the study at any time. Additional information regarding the interviews including the role of the researcher, quality and rigor, informed consent, and confidentiality are discussed in detail in *Section 3.2* and *Section 3.3*.

Mind Mapping is a graphic technique, that expresses radiant thinking, by allowing a user to show relationships among various concepts and ideas on a single page (Buzan and Buzan 1996; Mento et al. 1999). Within a mind map, the subject of attention appears as the central image, with key themes (or words) radiating around the subject as branches. These branches can be represented utilizing a hierarchical system, with items of lesser importance radiating further from the main subject. The mind mapping technique is

utilized in this research to organize the coded qualitative data received from the case studies, interviews, and safety information. Organizing the data across the three data collection methods provides a singular graphical reference for the coded data. By organizing the information in a graphical hierarchy, the transition into a product model and sequence diagram is simplified. The collection of data through the qualitative analysis and the organization of that data through mind mapping, executes the requirements further discussed in *Objective No. 1*.

3.1.3.2. Data Transfer – Objective No. 2

Utilizing existing literature and simulated tests on a number of software, a data transference mechanism is identified. Execution of this Objective will aid in the mitigation of "handover issues" that are present within the industry.

3.1.3.3. DRPS Development – Objective No. 3

A *Product Model* is developed in order to further organize and add logic to the information obtained through the FACE reports, interviews, and safety information. The product model for this research utilizes the Unified Modeling Language (UML) Classification within a Class Diagram for the identified attributes as a static representation of a knowledge base.

Sequence Diagrams, a type of "Behavioral Diagram," presents how objects interact in a particular scenario over a period of time (Pilone and Pitman 2005; Visual Paradigm 2016). For this research, a sequence diagram is developed to present how the product model classes interact and the system retrieves the relevant safety information.

3.1.3.4. Conceptual GUI Development – Objective No. 3

Using Java Eclipse, a conceptual representation of the graphical user interface (GUI) for the system is developed. The conceptual GUI is utilized to visually present the interaction between the FM worker and the DRPS.

3.1.3.5. Validation Methods – Objective No. 4

Utilizing the Conceptual GUI in coordination with the UML Class and Sequence Diagrams, a *Proof of Concept* is presented through *Test Cases*.

Cognitive Walk-Through is utilized to present the proof of concept model to an industry expert in order to validate the developed system.

3.1.4. Limitations to Stated Methods

The following section address the limitations of this study within the context of the above stated methods.

Method Limitation No. 1: Interviews with industry professionals for data collection and validation will take place within driving distance of Blacksburg, VA and therefore may not include considerations applicable to other regions of the United States or internationally.

Method Limitation No. 2: Sample selection is purposive, with specific inclusion criteria, and is not intended to accommodate random sampling. Therefore, it is likely that certain sections of FM staff will not be utilized for data collection or validation.

3.2. The Role of the Researcher

The role of the researcher in this research is to study phenomena which has already taken place and evaluate qualitative data from these phenomena in order to provide a solution for the stated problems. To execute this task, the researcher maintains a role of observer and interviewer. The researcher and participants do not attempt recreate or engage in any of the events being evaluated, as this would create a significant safety hazard and would be irresponsible. As an interviewer, discussions take place regarding facility management (FM) protocol and safety with industry experts, recruited based on their knowledge of FM. There is no previous personal or work-related relationship with the individuals and because of this, power relationships are not an issue. In order to mitigate any perceived researcher bias, questions are guided only toward facts and opinions of the interviewee. Interjections by the interviewer only come in the form of follow-up questions/probes and clarifications. A conscious understanding by the researcher of how questions are asked, the tone in which they are stated, and the body language presented during the interview attempt to mitigate any response bias.

The lead researcher in this study has spent 6 years of his professional career working with a number of the individuals and documents that this research utilizes. This include construction documentation, working with Operations staff, project closeout and turnover, and building information modeling. This time in the field has allowed the author to draw on previous experience in order to execute the research being presented in this study.

3.3. Research Considerations

In any research study, considerations for quality and rigor must be made and enacted in order for findings to be valid. These considerations are even more important when the data collection methods for the study are qualitatively based. In addition, the use of human interaction through interviews carries ethical considerations in order to eliminate the potential for harm to the study participants. This section will present the methods that are used in order to maintain a trustworthy and ethical study.

3.3.1. Trustworthiness Using Qualitative Methods

Classical science has evolved around a core principal that studies must be refutable and replicable. Qualitative research, by nature, cannot be completely replicable as the data being collected relies on the reflexivity (awareness of self and others) of the researcher and the information being provided by the study participants at that moment in their experience. Anfara et al. (2002) describes this paradigm and offers a solution that has over time, emerged as a staple in qualitative research,

"We operate from the basic premise that how researchers account for and disclose their approach to all aspects of the research process are key to evaluating their work substantively and methodologically. Central to this premise are the core elements of classical science – refutability and replicability. Because one of the "difficulties" with qualitative research is the recognition that it is not, in the "classical science" sense, replicable, we recommend analytic openness on the grounds of refutability and freedom from bias."

To obtain the trustworthiness in qualitative research, Guba and Lincoln (1982) developed now widely accepted criteria as counterparts to the conventional (classical science) terms for assessing research quality and rigor. *Table 10* presents the conventional terms utilized in quantitative research and the qualitative counterpart developed by Guba and Lincoln. Additionally, this table defines what each term means in the qualitative sense.

Table 10: Comparison of Terms for Quality and Rigor (Adapted from Guba and Lincoln (1982)

Quantitative Term	Qualitative Term	Qualitative Term Definition
Internal Validity	Credibility	The relationship between the data of an inquiry and the phenomena those data represent. The data being produced through qualitative inquiry is providing believable results.
External Validity	Transferability	Provide "thick descriptions" through a vicarious experience and a transferability of hypotheses to a second context for the reader.
Reliability	Dependability	Stability in the data through analytical openness.
Objectivity	Confirmability	Verification of the data through methods of validation.

3.3.2. Trustworthiness in this Research

This research utilizes standards set forth by Guba and Lincoln during the data collection phase, as well as uses validation methods to maintain a commensurate level of quality and rigor to the overall framework development. During the data collection phase, the terminology Guba and Lincoln presented (credibility, transferability, dependability, and confirmability), can be utilized in order to insure trustworthiness when utilizing qualitative methods. *Table 11* presents the means that this research utilizes in order to maintain trustworthiness during data collection and analysis.

Table 11: Means of Trustworthiness in this Research

Credibility	Transferability	Dependability	Confirmability
•Triangulation •Member Checks	•Purposive Sampling •Thick Description	•Dependability Audit Trail •Triangulation	•Triangulation

- *Triangulation* cross-checks data and interpretations by verifying themes across from a variety of data sources. For this research, triangulation will occur by verifying themes across the interviews, case studies, and safety information. For example, FACE Reports are a retelling of how an accident occurred. This type of data is susceptible to human error and omission. Triangulation is utilized in order to mitigate an outlying occurrence in the data by comparing the data point to other sources.

- *Member Checks* verify the data and interpretations by checking with the individuals who solicited the information. In this study, member checks are used to verify the information gathered during

the interview phase. At the conclusion of the interview, the data received from the solicitor will be synthesized and presented to the solicitor. Upon review by the solicitor, a written confirmation, in the form of an email, verifies that the data and interpretations were understood and conveyed in a manner in which the solicitor intended. If data or interpretations were misrepresented, the information will be adjusted and noted in the record. Interviewees have two weeks (14 days) from the time the member check is sent out to verify the information. If no response is received by the interviewee within the two-week period, verification of the data and interpretations are implied.

- *Purposive Sampling* is utilized in this research. See Section 2.3.1 Research Methods for additional information on purposive sampling, including the inclusion criteria for this study.

- *Thick Description* is a technique used to provide enough information about a context to impart a vicarious experience and a transferability of a hypothesis to a second context for the reader. Thick descriptions are utilized in this research to depict the tone, surroundings, and feel of the interviews.

- *Dependability Audit Trail* is an accounting of the methodological steps and decisions made regarding the research. When a decision is made regarding the research, that decision is dated and noted in a running word document. The audit trail begins at the acceptance of the research proposal and is maintained throughout the data collection and data analysis phase of the research.

In addition to the means identified for the trustworthiness of the qualitative data collection of this research, a number of additional verifications, as shown in *Section 3.1.2 Research Methods*, are being utilized to demonstrate quality to the framework that this research develops. Continuous industry expert validation, proof of concepts, and a cognitive walk-through are steps beyond the data collection and analysis in order to validate the developed framework. All of these means are intended to produce a trustworthy study that maintains analytical openness and utilizes feedback from industry professional to validate the framework.

3.3.3. Ethical Considerations

This research follows the protocols and standards set forth by the Virginia Tech Internal Review Board (IRB) to verify compliance with the established standards of human research. Following the guidelines set forth by the IRB and following the accepted protocols for human research, ensures this research will not violate any ethical considerations including, informed consent, unwanted dissemination of personal or company information, recruitment, data collection, and data storage. Additionally, the use of methods such as member checks following an interview, eliminates unintended misrepresentation of the interviewee.

4. DATA COLLECTION, CATEGORIZATION, AND VALIDATION

As stated in Chapter 3, data collected in this research utilizes triangulation through Data Collection Interviews, FACE report coding, and safety information coding. This chapter details out how the coded information was obtained and the results from data collection. This information is utilized to develop safety inputs and protocols that are installed within the developed framework. With reference to *Figure 14*, six steps are defined:

1. The data collection methodology utilized in this research involves qualitative coding of FACE Reports, Data Collection interview transcripts, and safety literature. Using three forms of qualitative data sources allows for triangulation, adding the necessary rigor and validation to the identified safety inputs and protocols.

2. The relevant extracted information from each data source is organized into spreadsheets. The X-axis in each spreadsheet is specific to the data being collected from each source. However, the X-axis evolves as more data is collected (see step 6).

3. Organized data is coded and attributes are extracted.

4. Attributes can be segregated into safety inputs and protocols through knowledge development. These inputs and protocols are utilized within the framework for the three hazard types that this research is addressing; falls, exposure to harmful substances and environments, contact with/struck by.

5. Patterns and commonalities emerge among the three data sources.

6. As more sources were coded, patterns began to emerge and commonalities within the three sources became apparent. As patterns between the data sources began to link, an iterative update of the spreadsheet headings was executed in order to further process the data.

The following sections provide details to the data collection sources and examples of how safety inputs and protocols are extracted from the text for each of the three sources of relevant safety information.
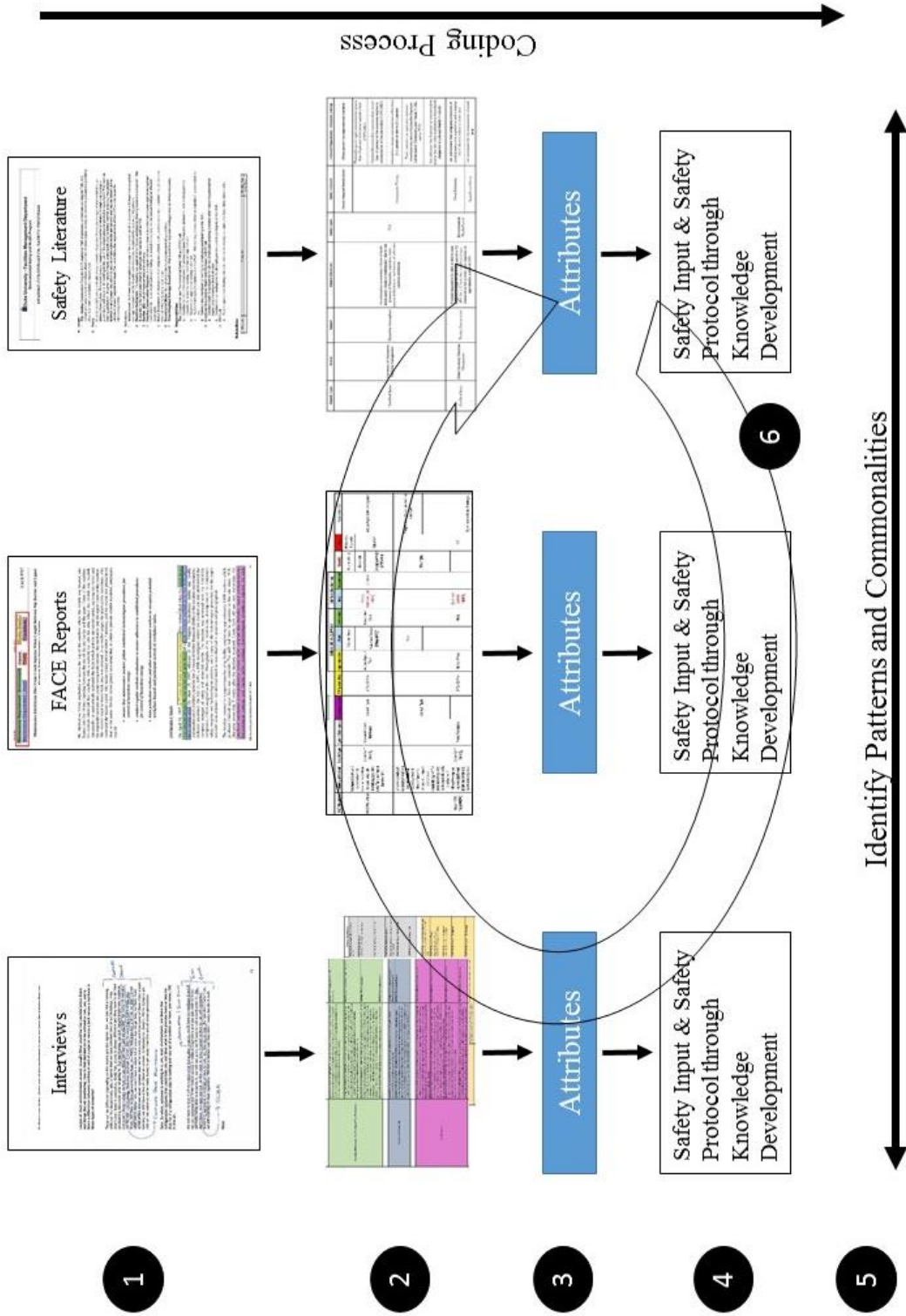
Figure 14: Phase I Define

4.1. FACE Reports

Fatality Assessment and Control Evaluations or FACE Reports (National Institute for Occupational Safety and Health 2014), provide detailed reviews of fatal accidents that take place in a work environment. Through the FACE program, the National Institute of Safety and Health (NIOSH) conducts investigations into employer-reported fatal incidence. These detailed reports provide demographic, work environment, accident, and prevention information for each incident. In order to utilize FACE reports for this research, a comprehensive review of the 613 records available for review on the Center for Disease Control and Prevention – NIOSH website was completed, identifying facility management specific incidences for detailed evaluation (National Institute for Occupational Safety and Health 2014). Of the 613 available records, 34 records were specific to the maintenance and repair of a facility falling under the three categories that this research is reviewing. These 34 records were identified through the use of the "find" function using the terms, "facility management," "maintenance," and "repair." The search results that yielded farming data were not utilized and are not included in the 34 records. The breakdown of the FACE reports coded in this research are presented in *Table 12*

Table 12: Breakdown of FACE Reports Utilized in this Research

#	Falls	Contact With/Struck By	Harmful Environments
1	California Report 07CA007	FACE 9717 In-House	California Report 11CA008
2	FACE Report No. 9013	Oregon FACE Report 04OR003	FACE Report No. 9104
3	Massachusetts 11-MA-008-01	Oregon FACE Report 05OR008	FACE Report No. 9014
4	FACE Report No. 9801	California Report 00CA007	FACE Report No. 8928
5	FACE Report No. 9104	New York Report 02NY096	Colorado Report 91CO074
6	Michigan Report No. 10MI006	California Report 98CA004	Oregon Report 04OR037
7	NY FACE Report 07NY080	California Report 00CA009	Alaska FACE Report 91-13
8	FACE Report 9621	Virginia FACE Report No. 9239	Washington 04WA080
9	Texas Report 98TX13301	FACE Report No. 2002-05	FACE Report No. 88-21
10	FACE Report 9506	FACE Report No. 2006-02	FACE Report No. 8610
11			California Report 06CA008
12			FACE Report 89-18
13			FACE Report 91-32
14			FACE Report 89-19

Qualitative analysis of the FACE Reports used a color scheme in order to identify the applicable codes. For example, a yellow highlight indicates "Worker Details," while a purple highlight references a "Procedural Failure." In order to begin to identify patterns and correlate the data collected from the FACE Reports, an Excel spreadsheet was used for organizational purposes. During the organizational phase of the FACE Report data collection, an iterative process was used in order to identify the appropriate categories in the

X-axis of the spreadsheet. As more FACE Reports were read and organized the nodes evolved. *Figure 15* graphically presents the evolution of the X-axis nodes, while *Figure 16* presents an image of the spreadsheet evolution.
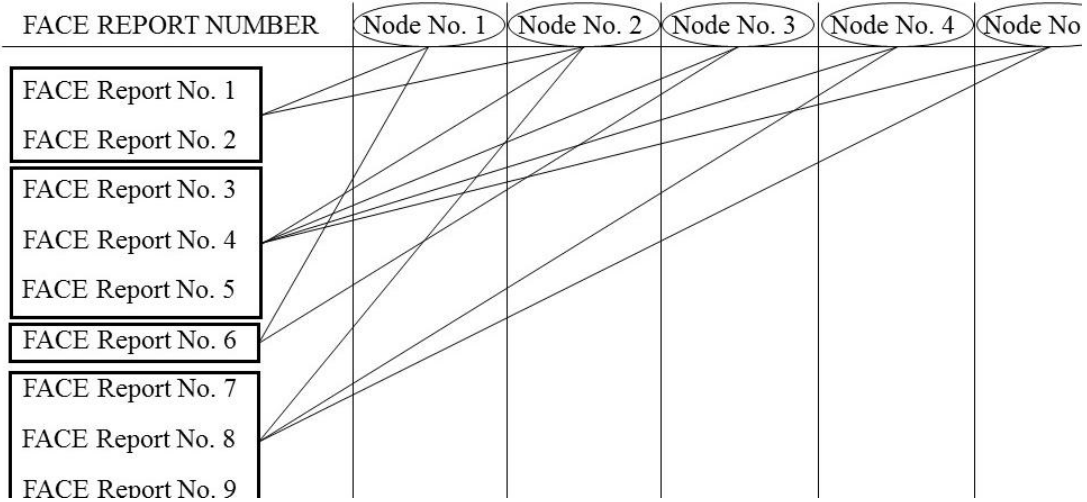
Figure 15: Evolution of the Main X-axis Nodes in the FACE Report Spreadsheet
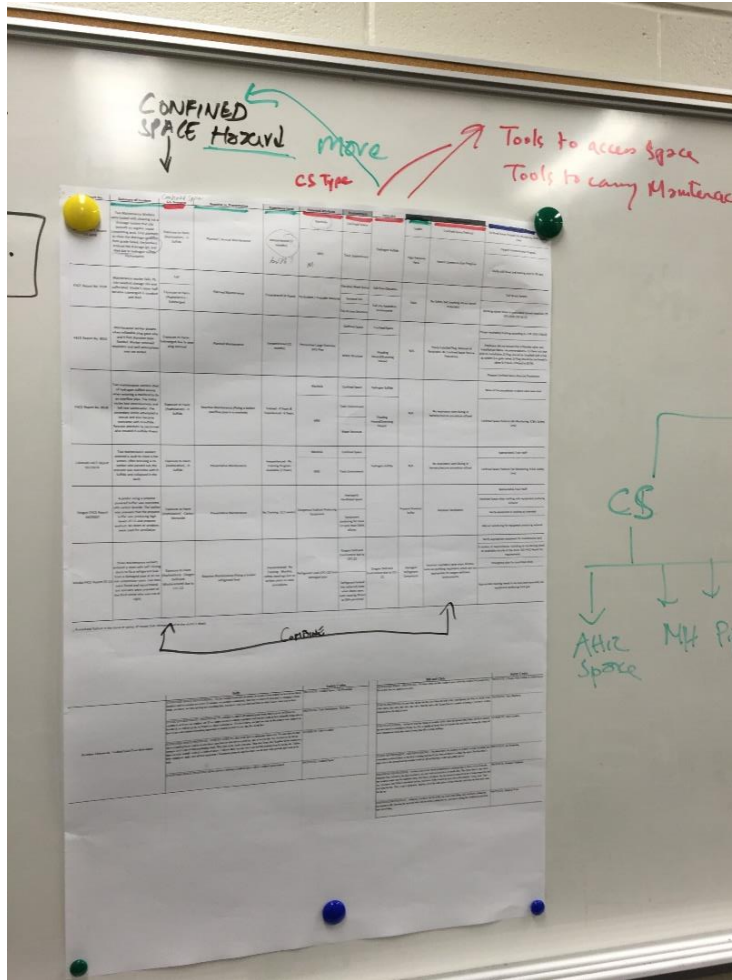
Figure 16: Image of the FACE Report Spreadsheet Evolution

Ultimately, the X-axis nodes evolved into the following eleven categories:

1. FACE Report Identification Number
2. Summary of Incident
3. Tools to Carry Out Maintenance
4. Tools to Access Space
5. Reactive vs. Preventative Maintenance
6. Experience Level
7. Potential Attribute(s)
8. Environment
9. Hazard(s)
10. Procedural Failure(s)
11. Hazard Control(s)

Figure 17 presents a single, contact with/struck by FACE Report regarding a maintenance electrician who was crushed to death when a limit switch was activated by the victim, who was leaning into the equipment (National Institute for Occupational Safety and Health 1997). In addition, the figure features how the information is organized within the Excel spreadsheet. The following is the summary as described in the FACE Report.

"On April 18, 1997, a 37-year-old male maintenance electrician (the victim died when his lower torso was crushed between the nip barrier (a wire-mesh gate) and the upper frame of a paper rewinder machine at a paper-manufacturing facility. Without first de-energizing, locking out, and tagging the machine, the victim began to replace the arm for the limit switch that controlled upward movement of the nip barrier. He climbed an 8-foot stepladder to access the top of the machine where the switch was located, and leaned into the 16-inch opening between the top of the nip barrier and the upper frame of the machine…"

Extracted Text

"…a 37-year-old male maintenance electrician (the victim) died when his lower torso was crushed between the nip barrier and upper frame of a paper rewinder machine as he was replacing a limit switch arm… worked for the company for about 8 years."

"…8-foot fiberglass ladder… screwdriver in right hand.

"…was leaning into the 16-inch opening between the nip barrier and the machine's upper frame, with his waist level with the top of the barrier. The 6th hand saw the victim make a forward motion with the screwdriver. The nip barrier immediately raised, catching the victim and the stepladder, lifting and compressing both between the nip barrier and the upper frame. The victim's waist to lower back area was crushed."

"Recommendation #1: Employers should ensure that maintenance workers follow established lockout/tagout procedures for control of hazardous energy."

Coded Data

FM Worker Detail
37-year-old male maintenance electrician
8 years w/ company

Asset
Paper rewinder machine with limit switch

Tools
8ft fiberglass ladder & screwdriver

Fatality Type
Contact with / Struck By

Environment
Elevated workspace

Hazard
Hazardous Energy
Pinch Point(s)
Sensory Automation (Limit Switch)

Procedural Failure
Lockout / Tagout

Type of Maintenance
Reactive

FACE Report No.	Summary of Incident	Fatality Type	Type of Maintenance	Procedural Failure	FM Worker Detail	Experience Level	Asset	Environment	Asset	Environment	Additional Nodes [2]	Hazard(s)	Tools	Hazard Controls
FACE 9717 In-House	Maintenance Electrician is crushed between a nip barrier and the upper frame of a paper rewinder after manually engaging a limit switch. Task was to replace limit switch arm.	Contact With / Struck By	Unplanned / Reactive Maintenance	Lockout / Tagout	37 Year Old Male	Seasoned/Expert - 8 Years	Automated Motion / Maintenance Requires Entrance (MRE)	Elevated Work Space	Sensory Automation (Limit Switch)	Lift System	Manual Automation (Switch, Lever, Press) / Manual Override	Hazardous Energy / Pinch Points / Sensory Automation (Limit Switch)	8ft Fiberglass Step Ladder / Screwdriver	Lockout / Tagout Automated Equipment

Figure 17: **Coding Methodology of FACE Report – Example**

Based on the details provided from the FACE Report and the coded data, the following safety information can be extracted:

- Lockout / Tagout
- Hazardous Energy
- Pinch Points
- Automated Equipment (Limit Switch)
- Lift System (Ladder)

Additional analysis of the extracted safety data yields two types of information, *safety input* and *safety protocol* data. Safety input data are the inherent risks associated with a work activity, while safety protocol data are the mitigation techniques utilized in order to avoid the risk(s). To decipher which category the above attributes fall under, a *knowledge* category identifies preliminary links between the inputs and the protocols. These preliminary links will be greatly expanded upon during the Mind Mapping and DRPS development, but initially serve as an organizational step. *Table 13* presents the safety attributes within the designated category for the above example. "Hazard Type" indicates which of the three hazard areas these attributes fall under:

- Harmful Substance and Environment – HARM
- Contact With / Struck By – CW/SB
- Falls – FALL

Table 13: Safety Attributes within the Designated Category – FACE Reports

Safety Input (Hazard Type)	Knowledge	Safety Protocol	Knowledge
Hazardous Energy (HARM)	Relates to Lockout/Tagout	Lockout / Tagout	Relates to HARM and CW/SB Inputs
Pinch Points (CW/SB)	Relates to Lockout/Tagout	Lift System- Ladder	Relates to FALL Inputs
Automated Equipment- Limit Switch (CW/SB)	Relates to Lockout/Tagout		

By continuing the process of FACE report data collection and analysis for all 34 records, a comprehensive list of safety inputs and knowledge can be developed. *Appendix 10.2 – Appendix 10.5* presents all of the FACE Report data collection and analysis sheets.

4.2. Data Collection Interviews

This research utilizes two types of interviews in order to obtain safety inputs and to validate the information developed from the three data collection instruments. These two types of interviews provide necessary trustworthiness in qualitative research. The interviews were conducted in the manner stated in *Section 3.1.2 Research Methods* and utilized purposive sampling, member checks, and thick descriptions. The first interview utilized was the Data Collection Interview, as described in *Section 3.1.3.1 Data Collection & Organization – Objective 1*. The Data Collection Interview is used to identify safety inputs and protocols to be input into the framework. *Table 14* presents the professional information for the six participants that were included in the Data Collection Interviews. Three data collection interviews took place, two in August 2015 and one in February 2016. In an effort to cover a wide range of expert opinions, participant job titles and responsibility range from upper management to skilled labor. As stated in Chapter 3, the participant's names and companies have been excluded from this list in order to maintain anonymity. All the names presented in *Table 14* are randomly selected pseudonyms.

Table 14: Data Collection Interview Participant Information

#	Date Interviewed	Pseudonym	Position	Company Type	Staff Size
1	8/11/15	Sally	Safety Manager for Facilities Management	Large University: Southeast Region USA	500+
2	8/13/15	Chris	Director of Utilities and Energy	Large University: Southeast Region USA	30+
	8/13/15	Bill	Assistant Director of Utilities and Energy	Large University: Southeast Region USA	30+
3	2/4/16	Joe	Operations Manager	Civic Center w/ Arena & Ice Rink Southeast Region USA	100-150
	2/4/16	Dan	Maintenance Supervisor	Civic Center w/ Arena & Ice Rink Southeast Region USA	~30
	2/4/16	Tim	Electrician	Civic Center w/ Arena & Ice Rink Southeast Region USA	2

Upon completion of the interviews, the recordings were transcribed into a word document. This Word document was coded by hand and placed into a spreadsheet for organization and identification of applicable safety attributes. Along with demographic information about the interviewee, relevant quotes from the interview were segregated into six categories:

1. Falls
2. Hazardous Environment – Electrical
3. Hazardous Environment – Confined Space / Toxic Environment
4. Contact With / Struck By
5. Dual Processes (Statements that refer to more than one hazard in a single FM task)
6. Outside Factors to Safety – Environment

By aggregating full quotes into the six categories, applicable safety input and safety protocol data could then be extracted within the proper context. *Figure 18* presents a sample of the coding methodology utilized for the Data Collection interviews and organization of the extracted text and coded data in an Excel Spreadsheet.

Extracted Text   **Coded Data**

"First and foremost, they are going to look at the plans if they don't know where the line feeds already are and they are going to make every effort to shut it down and make sure that it's lockedout/tagged out and dead prior to them working on it."

Protocol
Lockout / Tagout

Input
Disconnect Location

"We are constantly doing the lockout/tagout of HVAC systems for that because those are all automated"

Protocol
Lockout / Tagout

Input
Automated Equipment (Full)

"..they're gonna have to look first of all and figure out what piece of equipment do they need. Do they need a man lift, do they need a nifty lift, do they need the eighty foot lift or can they do it all from a ladder. If they can do it from a ladder, which ladder is appropriate."

Protocol
Lift System

Input
Maintenance Elevation

"So, they pull out their maps and figure out where the (pipe is), they've got maps in their trucks. So once they hit the site they see where the leak is, they start figuring out where to cut the water, what valves, this valve, this valve, this valve. Shut the valves off. Then it's a matter of getting a, you know, system drained down, the leak located."

Protocol
Lift System

Input
Maintenance Elevation

	Sally	Safety Codes
Falls	[MAN POWER REQUIREMENT - PROTOCOL] ...if their working at heights, usually there's more than two people. There's going to be at least one person on the ground, one person up high, usually two people on the ground.	PROTOCOL: 2 people when working at heights
	[FALLS PROCEDURE] ..they're gonna have to look first of all and figure out what piece of equipment do they need. Do they need a man lift, do they need a nifty lift, do they need the eighty foot lift or can they do it all from a ladder. If they can do it from a ladder, which ladder is appropriate. We've had some issues with this in the past but they've got better ladders now. And they can actually, some of them actually have cages on top of them where they can get out and work on the top of the ladder instead of having to pull a lift over.	PROTOCOL: Lift System INPUT: Working Height
	[LIFT SYSTEM - BUCKET TRUCK PROTOCOL] ...if they're having to use a lift they know they have to have fall protection training and they have to have training in how to operate that lift. Both of which is about 12 hours of the training right there. So, they're getting that and they know if they have the training or they don't have the training.	PROTOCOL: Lift System - Bucket Truck
	[HARNESS SAFETY] They won't have a safety harness if they don't have the training.	PROTOCOL: Fall Arrest System
	[LIFT SYSTEM - BUCKET TRUCK] ...a lot of their work is gonna be done from the bucket truck and they are always tied off in the bucket truck.	PROTOCOL: Lift System - Bucket Truck - Fall Arrest System
	[LIFT SYSTEM - BUCKET TRUCK] ...miles per hour is going to based on what the bucket truck can handle or the manlift can handle at this point about 25 miles per hour and we look at the airport numbers, twenty-five miles per hour is pretty darn high winds and we'll probably shut it down at more like fifteen because the guys are so uncomfortable being up there	PROTOCOL: Lift System - Bucket Truck
	[FALL ANCHOR POINTS] ...we don't know where (the fall anchor points) are on all our buildings; maybe all our buildings don't have them cause their all so old. And since we're a Non-OSHA state we have to fight to get those things put in place.	INPUT: Anchor Points (Y/N)

Figure 18: Coded Data Collection Interview and Organization – Example

Based on the above examples additional safety inputs and safety protocols can be extracted as presented in *Table 15*. In some instances, redundant inputs and protocols from the FACE Report and safety literature examples are identified. The redundancy within the data collection represents the confirmation of a data point between two or more sources, known as triangulation.

Table 15: Safety Attributes within the Designated Category – Data Collection Interviews

Safety Input (Hazard Type)	Knowledge	Safety Protocol	Knowledge
Disconnect Location (HARM & CW/SB)	Relates to Lockout/Tagout	Lockout / Tagout	Relates to HARM and CW/SB Inputs
Automated Equipment (CW/SB)	Relates to Lockout/Tagout	Lift System-Man lift & Ladder	Relates to FALL Inputs
Maintenance Elevation (FALL)	Relates to Lift Systems		

The Data Collection interview questions and the data collection and analysis spreadsheets for the three interview transcripts are presented in *Appendix 10.6 – Appendix 10.9*.

4.3. Safety Literature

Safety literature in the context of this research is any document that could provide insight into the safe maintenance of a facility applicable to the three hazard types that this research attempts to mitigate – falls, contact with / struck by, and exposure to harmful substances or environments. These documents could be a safety checklist, handbook, O&M manual, OSHA pamphlet, etc. Review of the safety literature yielded seven categories used to code the information:

1. Hazard Type (Falls, Contact With / Struck By, Harmful Substances and Environments)
2. Source
3. Hazard
4. Hazard Definition
5. Safety Input
6. Safety Protocol
7. Protocol Requirements / Minimum Testing

Table 16 presents all of the safety information sources utilized in this research. In correlation with the other two sources of safety data, collection of safety inputs and protocols ceased when data saturation became apparent.

Safety Information Data Collection Sources	
Environmental Protection Agency (2015)	United States Department of Labor (2007)
Duke University (2012) FM Safety Sheet	United States Department of Labor (2011)
Creighton University Facilities Management (2010)	Department of the Navy (2013)
University of Minnesota Facilities Management (2008)	Coastal Carolina University (2003)
Alberta Government (2014)	Office of Compliance (2010)

Figure 19 presents examples from Duke University (2012) and University of Maryland Facilities Management (2012) of the type of safety literature utilized in order to obtain additional safety inputs and safety protocols and how the data was organized within the Excel Spreadsheet.
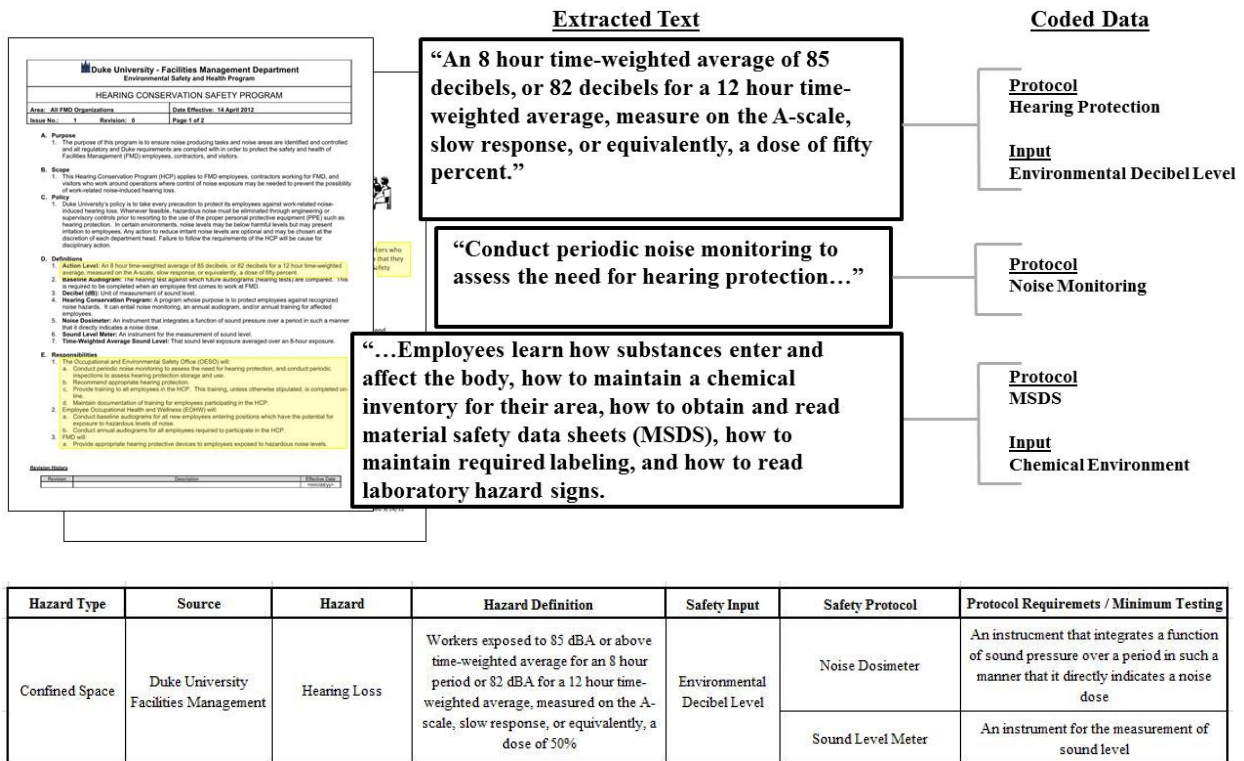
Figure 19: Coded Safety Literature and Organization - Example

From the above safety literature examples we can identify additional safety inputs and safety protocols applicable to the three safety hazards that this research is evaluating. *Table 17* presents the extracted data from the examples.

Table 17: Safety Attributes within the Designated Category – Safety Literature

Safety Input (Hazard Type)	Knowledge	Safety Protocol	Knowledge
Environment Decibel Level (HARM)	Relates to Hearing Protection & Noise Mon.	Hearing Protection	Relates to HARM Inputs
Chemical Environment (HARM)	Relates to MSDS Protocols	SDS Protocol	Relates to HARM Inputs
		Noise Monitoring	Relates to HARM Inputs

Appendix 10.10 presents the safety information data collection and analysis spreadsheet.

4.4. Data Categorization and Mind Mapping

Upon reaching data saturation, the acquired safety data from the three methods of data collection is comprehensively coded, renamed, and categorized into the three specific hazard areas that this research is attempting to mitigate. The identified FM hazards, known as *safety inputs*, are associated with applicable hazard mitigation techniques (safety protocols), known as *knowledge*. In addition, production information for the safety inputs, known as *data sourcing*, is identified. Production encompasses information relating to the identification of the phase of the building lifecycle the information is produced, who is typically responsible for the creation of the asset or area causing the hazard, and what method of data transfer is likely for that information. Data sourcing information was correlated through constructivist theory and is a result of author experience. Using the data sourcing information in correlation with the safety inputs and associated protocols creates the backbone for the data loading and transfer phases addressed in Chapter 5. *Table 18* presents a partial example of the initial categorization of the HARM safety inputs and protocols.

In order to further organize the data, the safety inputs and protocols is placed into mind maps. *Figure 20* presents an example Mind Map of the Contact With/Struck By (CW/SB) category. In order to develop the Mind Maps, the safety inputs and protocols were further structured by an inherent hierarchy. For example, "Hazardous Energy" is identified through the data collection as a safety input requiring mitigation during an FM task. In order to mitigate "Hazardous Energy," a FM worker would need to acquire additional information regarding the hazardous energy, such as "Voltage", "Disconnect Location", etc. Structuring the safety information into mind maps aids in the establishment of the Asset Safety Identification Tool (Chapter 5) and the Data Retrieval and Processing System (Chapter 6), while secondarily acting as a

graphical tool for industry professionals to use during the data validation interviews presented in *Section 4.5 Data Validation*.

Table 18: Initial Categorization Safety Inputs, Data Sourcing, and Protocols (Partial)

HARMFUL ENVIRONMENTS & SUBSTANCES (HARM)

| Safety Input | DATA SOURCING | | | |
	Typical Production Phase	Primary Developer	Method of Transfer	*Knowledge*: Relates to Safety Protocol
Hazardous Energy	Design	A/E	Native BIM Model	Lockout/Tagout
				Hot Sticks/Metering
				Permits
				Arc Flash Protection
Elec. Disconnect Location(s)	Design	A/E	Native BIM Model	Lockout/Tagout
Voltage	Design	A/E	Native BIM Model	Lockout/Tagout
				Arc Flash Protection
				Permits
				Hot Sticks/Metering

Figure 20: Initial Mind Map – Contact With / Struck By Example (CW/SB)

4.5. Data Validation

In order to identify a comprehensive list of safety inputs, protocols, and typical data sourcing, industry professionals are utilized to validate the collected data. This is executed through the Data Validation interview as presented in *Section 3.1.3.1 Data Collection & Organization – Objective 1*. ***Table 19*** presents the participants that were utilized for the Data Validation interviews.

Table 19: Data Validation Interview Participants

Date Interviewed	Pseudonym	Position	Company Type
6/17/16	Ryan	Facilities Safety Inspector	Large University: East Region USA
6/21/16	Sally	Safety Manager for Facilities Management	Large University: Southeast Region USA

Utilizing triangulation through the three methods of data collection and the use of Data Validation interviews for the validation of the collected data, the developed safety inputs and protocols can now be utilized by the safety framework. The complete list of the 28 safety inputs, associated knowledge, and sourcing is presented in ***Table 20***. ***Appendix 10.12 Data Validation Interview Data Adjustments / Additions*** presents the initial data inputs, sourcing, and protocols with the variations made to the list through the Data Validation interviews.

Table 20: Safety Inputs and Protocols

HARMFUL ENVIRONMENTS & SUBSTANCES (HARM)

Safety Input	DATA SOURCING			*Knowledge*: Relates to Safety Protocol
	Typical Production Phase	Primary Developer	Method of Transfer	
Hazardous Energy	Design	A/E	Native BIM Model	Lockout/Tagout
				Hot Sticks/Metering
				Permits
				Arc Flash Protection
Elec. Disconnect Location(s)	Design	A/E	Native BIM Model	Lockout/Tagout
Voltage	Design	A/E	Native BIM Model	Lockout/Tagout
				Arc Flash Protection
				Permits
				Hot Sticks/Metering
Approx. Disconnect Distance	Design	A/E	Native BIM Model	Lockout/Tagout

Asbestos Potential	FM	FM Staff	Direct Input	Asbestos Management
				Respiratory Protection
Environment Decibel Level	Construction	Manufacturer / Subcontractor	Non-3D	Hearing Protection / Noise Dampening
				Noise Monitoring
Environmental Air Quality	Design	A/E	Native BIM Model	SDS / Chemical Management
				Respiratory Protection
				Refrigerant Management
				PCB Management
				Silica Management
				Asbestos Management
				Lead Management
				Permits
Manhole / Tank / Confined Space	Design	A/E	Native BIM Model	Hearing Protection / Noise Dampening
				Noise Monitoring
				SDS / Chemical Management
				Air Monitoring
				Temperature Monitoring
				Valve Location(s)
				Confined Space Protocol
				Permits
				Ventilation
Oxygen Deficient / Oxygen Enriched / Carbon Monoxide Environment	Design	A/E	Native BIM Model	Permits
				Air Monitoring
				Ventilation
				Respiratory Protection
Particulate Environment	Design	A/E	Native BIM Model	Air Monitoring
				Ventilation
				Respiratory Protection
Exhaust Producing Asset	FM	FM Staff	Direct Input	Ventilation
Flooding Potential	Design	A/E	Native BIM Model	Inflatable Valve
				Valve Location
				Safety Line
Hazardous Asset Temperature	Design	A/E	Native BIM Model	Burn Mitigation / Frostbite Mitigation / Hypo (Hyper)thermia

Outdoor Environment	Design	A/E	Native BIM Model	Weather Considerations - Heat, Cold, Precipitation, Wind
				Nature - Animals, Allergens, Plant Life
Lead Potential	FM	FM Staff	Direct Input	Lead Management
				Respiratory Protection
Hazardous Chemical Production / Storage	Design	A/E	Native BIM Model	SDS / Chemical Management
				Air Monitoring
				Secondary Containment
				Ventilation
				Respiratory Protection
				Valve Location
Radiation	Design	A/E	Native BIM Model	Monitoring
				Radiation Management
Polychlorinated Biphenyls (PCB) Potential	FM	FM Staff	Direct Input	PCB Management
				Respiratory Protection

FALLS (FALL)

	DATA SOURCING			
Safety Input	Typical Production Phase	Primary Developer	Method of Transfer	*Knowledge*: Relates to Safety Protocol
Maintenance Requires Lift System	All	All	Native BIM Model, Non-3D, or Direct Input	Lift System
				Working Height
				Fall Arrest System / Anchorage
Roof / Deck	Design	A/E	Native BIM Model	Lift System
				Chemical Venting (Industrial Hygiene)
				Fall Arrest System / Anchorage
				Barricading / Notification
				Outdoor Environment
Ledge / Hole	Design	A/E	Native BIM Model	Lift System
				Fall Arrest System / Anchorage
				Safety Line
				Barricading / Notification

CONTACT WITH / STRUCK BY (CW/SB)

| Safety Input | DATA SOURCING | | | |
	Typical Production Phase	Primary Developer	Method of Transfer	*Knowledge*: Relates to Safety Protocol
Manual Crushing/Rotating/Slicing Mechanism	Construction	Manufacturer / Subcontractor	Native BIM Model or Non-3D	Lockout/Tagout
				Barricading / Notification
Automated Crushing/Rotating/Slicing Mechanism	Construction	Manufacturer / Subcontractor	Native BIM Model or Non-3D	Lockout/Tagout
				Hot Sticks/Metering
				Permits
				Barricading / Notification
Suction / Pressure Line	Design	A/E	Native BIM Model	Safety Line
				Burn Mitigation / Frostbite Mitigation / Hypo (Hyper)thermia
				Valve Location(s)
				Barricading / Notification
Valve Location(s)	Design	A/E	Native BIM Model	Line Isolation
Overhead Equipment	All	All	Native BIM Model, Non-3D, or Direct Input	Barricading / Notification
				Approach Vector
				Support Structure
				Equipment Weight
Approx. Valve Location Distances	Design	A/E	Native BIM Model	Line Isolation
Asset Support Structure	Design	A/E	Native BIM Model	Approach Vector

Mind Mapping is utilized to further structure the safety information. By organizing and categorizing (analyzing) the relevant safety properties, a hierarchy of information can be established. This hierarchy will aid in the rule and relationship development during the Analyze Phase of this research. *Figures 21, 22, & 23* present the hierarchical Mind Mapping of the three hazard types, utilizing the safety inputs and protocols in *Table 20.*
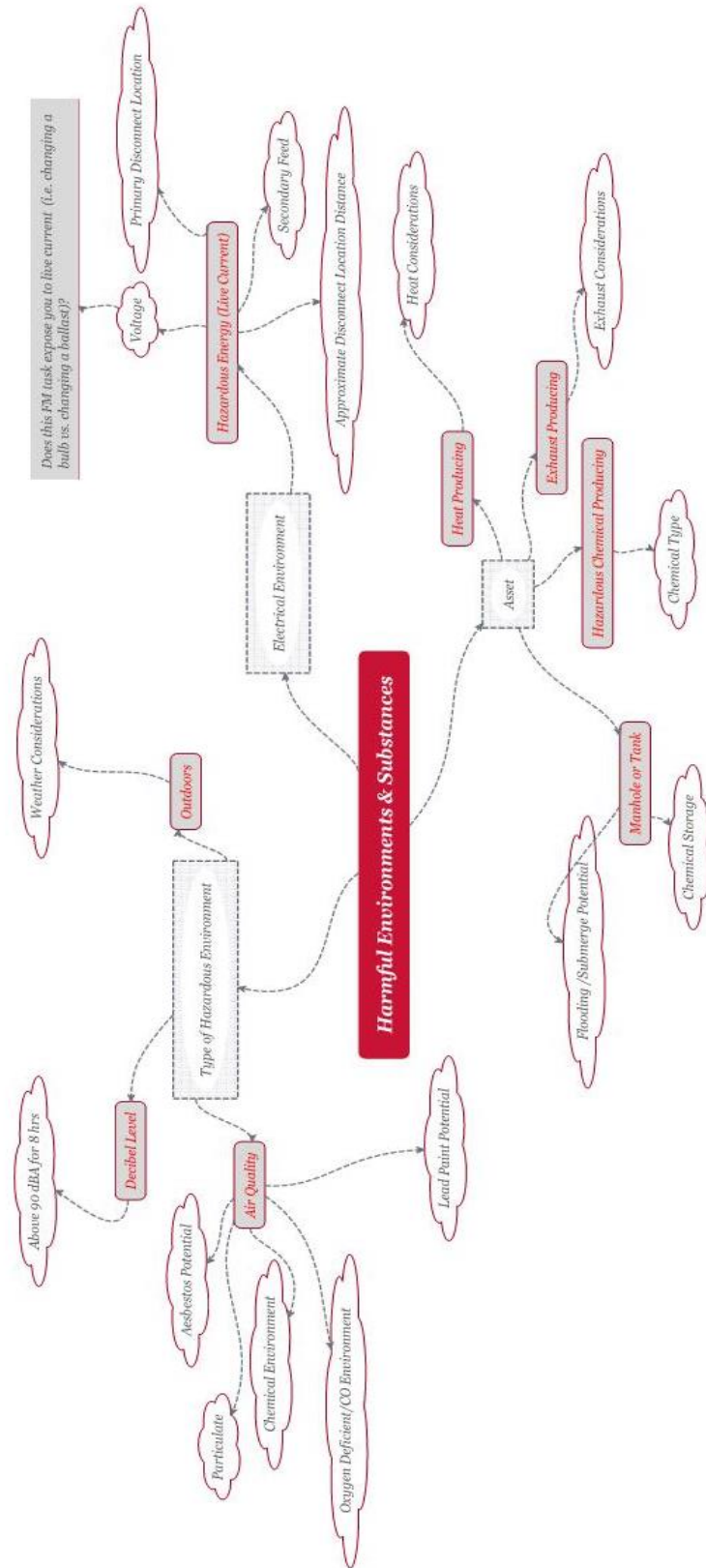
Figure 21: Mind Map– Harmful Environments and Substances (HARM)
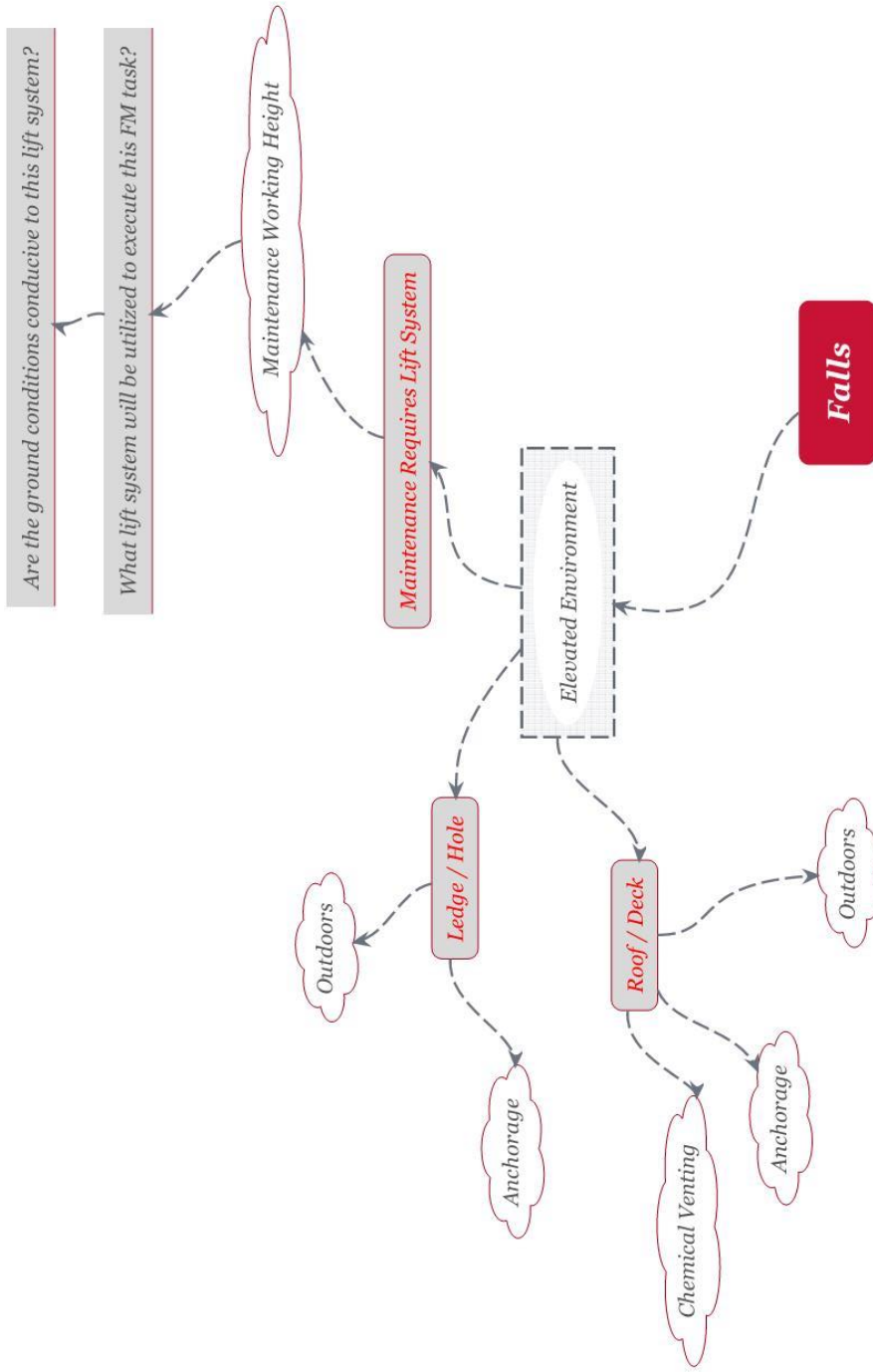
Figure 22: Mind Map– Falls (FALL)

Are the ground conditions conducive to this lift system?

What lift system will be utilized to execute this FM task?

Maintenance Working Height

Maintenance Requires Lift System

Falls

Elevated Environment

Ledge / Hole

Roof / Deck

Outdoors

Outdoors

Anchorage

Chemical Venting

Anchorage
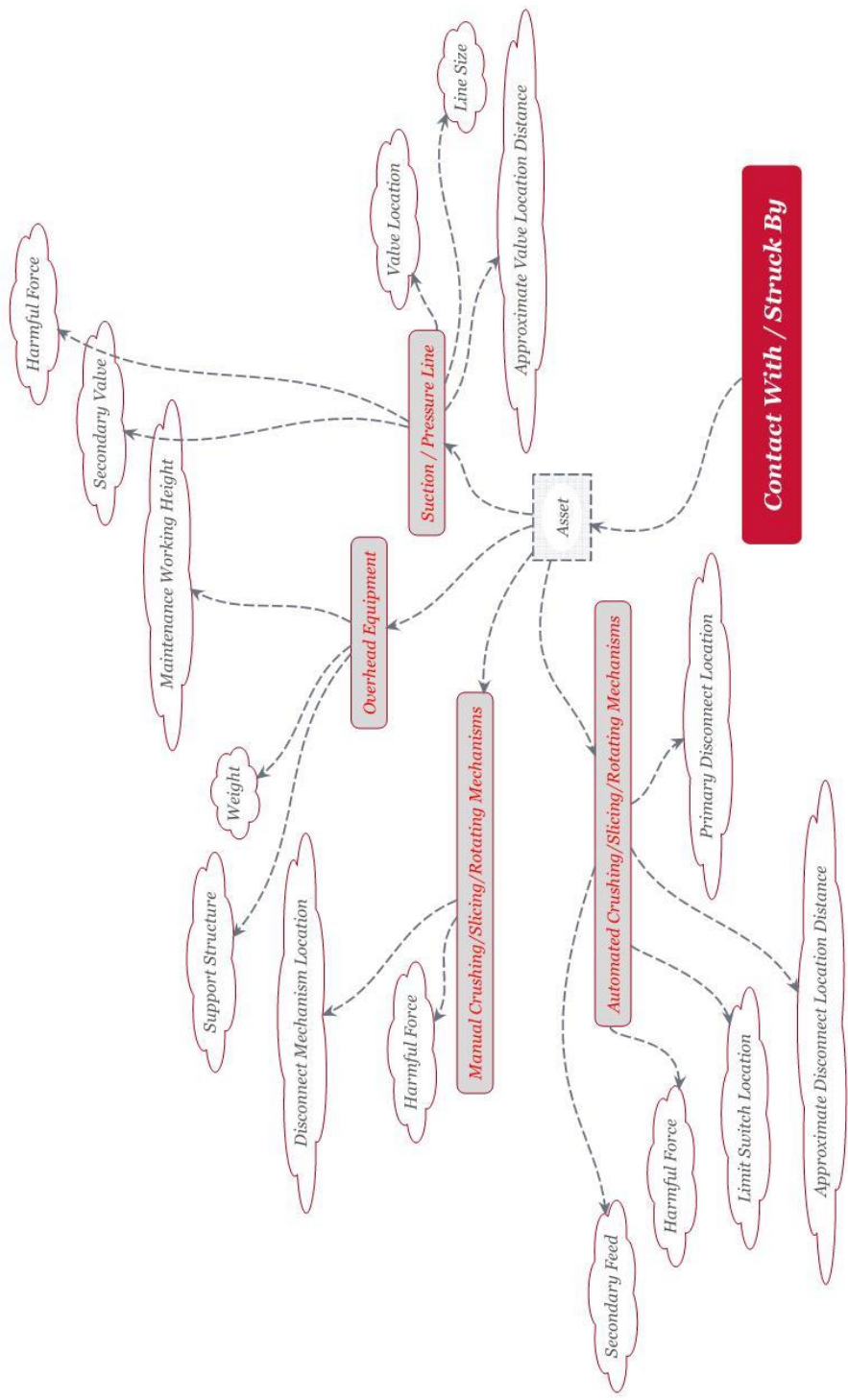
Figure 23: Mind Map– Contact With / Struck By (CW/SB)

72

4.6. Fundamental Safety Protocols

This chapter has identified the safety inputs, data sourcing, and associated protocols required to develop a DRPS that will present task-specific safety information to FM workers prior to a FM task. The information is intended to mitigate the hazard areas that this research addresses; however, during this data collection phase, three "Fundamental Safety Protocols" arose regardless of the hazard being mitigated or the task being executed. These three protocols transcend the task-specific nature of each task and apply in every scenario. Because these assumptions are required in every scenario regardless of hazard type being mitigated, they are not presented in *Table 20*. However, these inputs will always be presented in the protocol sheet produced by the DRPS (Chapter 6) regardless of the FM task being executed. They are as follows:

- PPE – A FM worker must be aware of the standard PPE requirements for executing maintenance tasks as required by OSHA or the facility of employment.

- Worker Qualifications – A FM worker must not attempt tasks that they are not qualified to execute. Research has shown that a portion of workers will attempt tasks that they have not been formally trained to conduct.

- Condition Assessment – Prior to the start of any FM task, a condition assessment of the asset requiring maintenance, the environment, and the tools being utilized must be completed. By nature, repair and maintenance work is needed when assets malfunction or break, potentially creating a hazard that could not be foreseen. For example, a broken pipe has created a sharp or serrated edge. This type of hazard is not a condition of the asset or environment, but of the energy causing the asset malfunction. Mitigation of this hazard could require additional tools, PPE, or approach vectors, but ultimately would be at the worker's discretion.

4.7. Data Collection Conclusions

Completion of the Measure Phase, using data validation through Data Validation interviews, allows for the knowledge collected in the Define Phase to be expanded upon and rules/logic to be developed under the Analyze Phase. These rules are implemented within the Design Phase and the system is validated through the Verify Phase. The rules and subsequent implementation are utilized in both the data loading (Chapter 5) and the DRPS (Chapter 6). The next Chapter will address two problems that the framework must address to properly function:

1. Comprehensively identify safety information required for each asset (*Problem Statement No. 1*).
2. Transfer the data from the design and construction phase to the FM phase.

5. DATA LOADING AND DATA TRANSFER

In order to utilize a system that delivers safety information to facility management staff efficiently, an understanding of where and how data is populated and stored throughout the lifecycle of a facility is of paramount importance. During the design and construction phase of a project, relevant safety information applicable to the safe maintenance of a facility is created. This information can be anything from basic location-based information to complex safety information. Regardless of the type of information, in order to deliver it comprehensively to the end user at the completion of a project, the requirements for what data is input and how the data is transferred needs to be addressed within the prime contract(s).

This chapter will address two phases of the overall proposed BIM-based safety framework as presented in *Figure 24.*
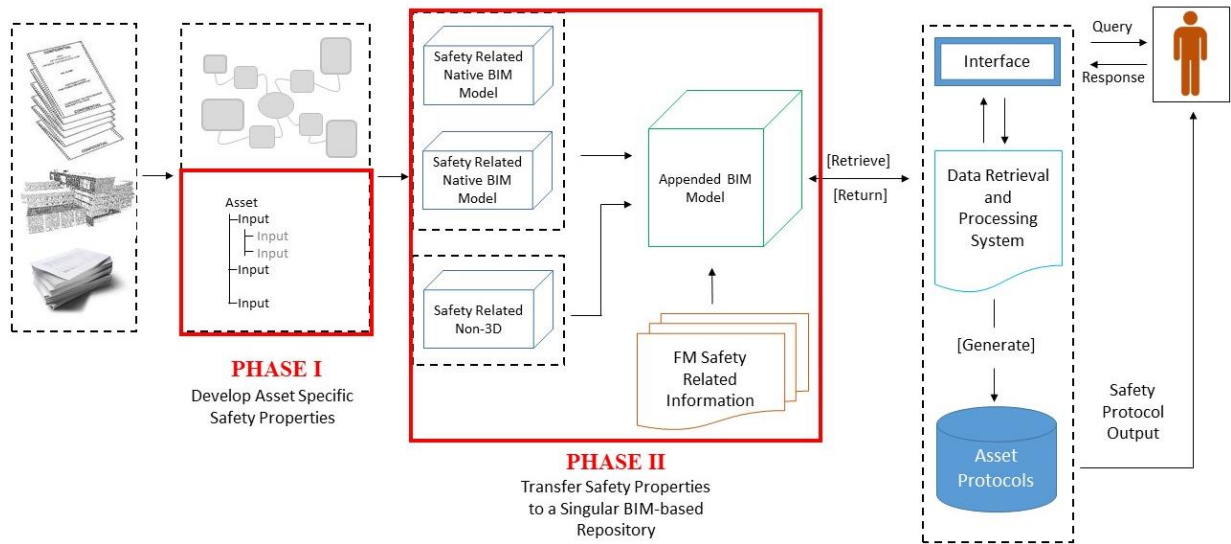
Figure 24: Phase I and Phase II of the BIM-Based Safety Framework

Phase I on *Figure 24* presents the Asset Safety Identification Tool (ASIT), a research tool developed in order to verify that the applicable safety inputs are assigned to each piece of equipment based on that equipment's asset group. This tool is utilized in order to create standard safety properties for each asset type relative to facilities management. As noted in *Problem Statement No. 1* of this research, "applicable project related safety information is often available at the handover stage from construction to facility management, but is not appropriately identified for facility management tasks." By standardizing the structure of relevant safety information for facility specific assets, a positive step is made towards mitigating safety concerns due to unidentified hazards for a given asset.

Phase II addresses data transfer – the mechanism that this research utilizes in order to transfer the relevant safety data from its data source to an appended Navisworks model. Although the safety data at this phase has already been identified and structured, the entities creating the information may utilize a number of different mechanisms to transfer the data. Phase II presents a dataflow mechanism utilizing existing software in order to store the data from multiple platforms to a single appended Navisworks model. This model acts as a safety data repository and a platform in which the DRPS can be integrated. The DRPS (Phase III) is presented in Chapter 6 Data Retrieval and Processing System (DRPS).

5.1. Phase I – Asset Safety Identification Tool (ASIT)

Chapter 4 of this research identified safety inputs that require a value assigned by the appropriate contract entity (data sourcing) prior to the utilization of the proposed DRPS. The Asset Safety Identification Tool (ASIT) presented in this section serves two purposes in support of the framework:

1. Develops standard, comprehensive safety information for specific FM asset groups.
2. Mitigates the unidentified and unstructured nature of safety information for specific assets when it is submitted to the FM Staff after the design and construction phase.

The ASIT is a tool that when executed can produce safety properties for an asset group by running the asset information through the automated spreadsheet. The ASIT guides the user through safety property development by requiring responses to queries based on the safety inputs identified in *Table 20: Safety Inputs and Protocols*. Evaluation of the safety inputs revealed a meronomy hierarchy (part-whole relationship) between the inputs. The ASIT captures and processes the meronomy hierarchy using conditional constructs in the form of "if-then" statements. Using information regarding an asset group, a standardized set of safety properties can be developed.

For example, consider three safety inputs identified in *Table 20*.

- `Hazardous Energy / Live Current`
- `Disconnect Location`
- `Voltage`

In order to perform maintenance on any asset, a FM worker would want to know if the asset requiring maintenance had hazardous energy, a disconnect location, and a voltage. However, evaluation of the inputs reveals the meronomy hierarchy. If the asset does not have `hazardous energy / live current`,

then there won't be a `disconnect location` or `voltage` to consider. Therefore, a formula can be developed to capture the relational data between the inputs.

```
IF ("Hazardous Energy / Live Current" = TRUE), THEN "Disconnect Location"
AND "Voltage" > ""
```

```
IF ("Hazardous Energy / Live Current" = FALSE), THEN ""
```

The above states that if the `Hazardous Energy / Live Current` is "True", then a value must be assigned to `Disconnect Location` and `Voltage`. If `Hazardous Energy / Live Current` is "False", no additional information is required.

The safety inputs within the ASIT are structured within three categories, primary, dependent, and independent. In the above example, `Hazardous Energy / Live Current` is a primary input. A "yes" response to a primary input, prompts the ASIT to require additional values through dependent inputs. The dependent inputs in the above example are `Disconnect Location` and `Voltage`. An independent input is similar to a primary input, requiring a "yes" or "no" response, but does not require additional information and therefore does not carry any dependent inputs. An example of an independent input from *Table 20* is `Outdoor Environment`. A "yes" response to `Outdoor Environment` notifies the FM user that the asset requiring maintenance is outdoors, but safety protocols associated with the outdoor environment (heat mitigation, cold mitigation, weather considerations, etc.) are variable and therefore are not be stored within the asset.

Using the ASIT, a FM department can develop a comprehensive list of safety properties based on the assets within their facility. These safety properties can then be stored within the singular BIM-based repository and values can be assigned for each asset (*Section 5.2 Data Transfer)*. Through continuous iteration and the use of diverse test cases, a standardized list of safety properties can be developed for all asset groups.

Appendix 10.13 presents the complete list of the interrelated safety inputs as they are formulated in the ASIT. *Figure 25* graphically identifies the various parts of the ASIT with a text description of each part on the following page.

INITIAL INPUT VERIFICATION SYSTEM (IIVS)

ITEM NAME	Framework Rules Functionality	Input Data
Panel P-1	**Background**	

PRIMARY INPUTS

Framework Rules Functionality	Input Data	Background
Manual Crushing / Rotating / Slicing Mechanism (YES / NO)	NO	NO REQUIRED INPUTS
Automated Crushing / Rotating / Slicing Mechanism (YES / NO)	NO	NO REQUIRED INPUTS
Suction / Pressure Line (YES / NO)	NO	NO REQUIRED INPUTS
Overhead Equipment (YES / NO)	NO	NO REQUIRED INPUTS
Environmental Air Quality Hazards Present (YES/NO)	NO	NO REQUIRED INPUTS
Environmental Decibel Level Hazard (YES/NO)	NO	NO REQUIRED INPUTS
Hazardous Energy / Live Current Present (YES/NO)	NO	NO REQUIRED INPUTS
Manhole or Tank (YES/NO)	NO	NO REQUIRED INPUTS
Hazardous Chemical Production Transmission (YES/NO)	NO	NO REQUIRED INPUTS
Radiation (YES/NO)	NO	NO REQUIRED INPUTS
Heat / Cold Producing Asset (YES/NO)	NO	NO REQUIRED INPUTS
Maintenance Requires Lift System (YES/NO)	NO	NO REQUIRED INPUTS

INDEPENDENT INPUTS

Framework Rules Functionality	Input Data	Background
Located on Roof / Deck (YES/NO)	NO	NO OUTPUT
Outdoor Environment (YES/NO)	NO	NO OUTPUT
Located at a Ledge / Hole (YES/NO)	NO	NO OUTPUT
Exahust Producing Asset (YES /NO)	NO	NO OUTPUT

DEPENDENT INPUTS

- Disconnect Mechanism Location (Manual Only)
- Limit Switch Location (Where In Equipment)
- Harmful Force (Y/N)
- Disconnect Location (Panel Number)
- Secondary Feed Location (Panel Number or None)
- Approximate Disconnect Distance (in feet)
- Valve Location (Valve Number)
- Secondary Valve Location (Valve Number or None)
- Line Size (in inches)
- Approximate Valve Location Distance (in feet)
- Harmful Temperature (Yes/No)
- Maintenance Working Height (in feet)
- Weight (in pounds)
- Support Structure Type (Platform, Threaded Rod, Etc.)
- Lead Present (Yes/No)
- Oxygen Deficient or Enriched / Carbon Monoxide Environment (Yes/No)
- Chemical No. 1 Present
- Chemical No. 2 Present (Harmful Chemical or None)
- Chemical No. 3 Present (Harmful Chemical or None)
- Particulate Present (Yes/No)
- Aesbestos Present (Yes/No)
- PCBs Present (Yes/No)
- Environmental Decibel Level (in dBA)
- Voltage (in volts)
- Flooding Potential Exists (Yes/No)
- Milliservions of Radiation
- Chemical Storage (YES or None)

INPUT VERIFICATION SYSTEM

Input	Status
MANUAL EQUIP / DISCONNECT	SYSTEM CHECK: ACCEPTABLE
MANUAL EQUIP / HARMFUL FORCE	SYSTEM CHECK: ACCEPTABLE
AUTOMATED EQUIP / DISCONNECT	SYSTEM CHECK: ACCEPTABLE
AUTOMATED EQUIP / 2nd FEED	SYSTEM CHECK: ACCEPTABLE
AUTOMATED EQUIP / LIMIT SWITCH	SYSTEM CHECK: ACCEPTABLE
AUTOMATED EQUIP / DISTANCE	SYSTEM CHECK: ACCEPTABLE
AUTOMATED EQUIP / HARMFUL FORCE	SYSTEM CHECK: ACCEPTABLE
SUCTION-PRESSURE LINE / VALVE LOCATION	SYSTEM CHECK: ACCEPTABLE
SUCTION-PRESSURE LINE / 2nd VALVE	SYSTEM CHECK: ACCEPTABLE
SUCTION-PRESSURE LINE / HARMFUL FORCE	SYSTEM CHECK: ACCEPTABLE
SUCTION-PRESSURE LINE / VALVE DISTANCE	SYSTEM CHECK: ACCEPTABLE
SUCTION-PRESSURE LINE / LINE SIZE	SYSTEM CHECK: ACCEPTABLE
SUCTION-PRESSURE / TEMP	SYSTEM CHECK: ACCEPTABLE
OVERHEAD EQUIP / MAINTENANCE ELEV	SYSTEM CHECK: ACCEPTABLE
OVERHEAD EQUIP / WEIGHT	SYSTEM CHECK: ACCEPTABLE
OVERHEAD EQUIP / SUPPORT STRUCTURE TYPE	SYSTEM CHECK: ACCEPTABLE
ENV AIR QUALITY / LEAD PAINT	SYSTEM CHECK: ACCEPTABLE
ENV AIR QUALITY / O-CO ENV	SYSTEM CHECK: ACCEPTABLE
ENV AIR QUALITY / CHEM NO. 1	SYSTEM CHECK: ACCEPTABLE
ENV AIR QUALITY / CHEM NO. 2	SYSTEM CHECK: ACCEPTABLE
ENV AIR QUALITY / CHEM NO. 3	SYSTEM CHECK: ACCEPTABLE
ENV AIR QUALITY / PARTICULATE	SYSTEM CHECK: ACCEPTABLE
ENV AIR QUALITY / AESBESTOS	SYSTEM CHECK: ACCEPTABLE
ENV AIR QUALITY / PCB	SYSTEM CHECK: ACCEPTABLE
ENV DECIBEL LEVEL / HEARING PROTECTION	SYSTEM CHECK: ACCEPTABLE
HAZARDOUS ENERGY / VOLTS	SYSTEM CHECK: ACCEPTABLE
HAZARDOUS ENERGY / DISCONNECT	SYSTEM CHECK: ACCEPTABLE
HAZARDOUS ENERGY / 2nd FEED	SYSTEM CHECK: ACCEPTABLE
HAZARDOUS ENERGY / DISTANCE	SYSTEM CHECK: ACCEPTABLE
MANHOLE-TANK / FLOOD	SYSTEM CHECK: ACCEPTABLE
MANHOLE-TANK / CHEMICAL	SYSTEM CHECK: ACCEPTABLE
MANHOLE-TANK / VALVE DISTANCE	SYSTEM CHECK: ACCEPTABLE
MANHOLE-TANK / VALVE	SYSTEM CHECK: ACCEPTABLE
MANHOLE-TANK / 2nd VALVE	SYSTEM CHECK: ACCEPTABLE
HAZ CHEM PRODUCTION / CHEM NO. 1	SYSTEM CHECK: ACCEPTABLE
HAZ CHEM PRODUCTION / CHEM NO. 2	SYSTEM CHECK: ACCEPTABLE
HAZ CHEM PRODUCTION / CHEM NO. 3	SYSTEM CHECK: ACCEPTABLE
MRLS / WORKING HEIGHT	SYSTEM CHECK: ACCEPTABLE
ROOF-DECK / OUTDOOR	SYSTEM CHECK: ACCEPTABLE
HARMFUL RADIATION	SYSTEM CHECK: ACCEPTABLE
CHEMICAL STORAGE	SYSTEM CHECK: ACCEPTABLE

Figure 25: ASIT Initial Layout

1. Item Name – The name of the piece of equipment as it is presented in the model. The name in this box must match the name in the model in order to enact the data transfer presented later in this chapter. Each piece of equipment requiring data loading will have its own worksheet within the spreadsheet.

2. Primary Inputs – A user will respond "Yes" or "No" to the 11 Primary Inputs. A "Yes" response in this section will prompt the user to input additional Dependent Inputs.

3. Dependent Inputs – Based on a "Yes" response to a Primary Input, asset specific information is needed in order to deliver detailed asset information to the FM user. The type of value is dictated by the Dependent Input. For example, the Dependent Input "Harmful Force" requires either a "Yes" or a "No" value, while the "Weight" input requires an input in pounds. *Figure 26* presents an example of an active Dependent Input section. In this example, the Primary Input "Hazardous Energy" is given a "Yes" response as Panel P-1 maintains an electrical current. Due to this "Yes" response, the user must populate the values for the associated "Dependent Inputs."

   a. Disconnect Location (Panel Number)
   b. Secondary Feed Location (Panel Number or None)
   c. Approximate Disconnect Distance (in feet)
   d. Voltage (in volts)

In order to aid the developer during the safety property identification phase, conditional formatting is used when a safety input requires a value. An example of this is presented in *Figure 26* with the inputs requiring a value being highlighted green.

4. Input Verification System (IVS) – In addition to the conditional formatting of the Dependent Inputs, the IVS runs a system check to verify that all of the inputs requiring values have been executed. When presenting a red color, a value is missing for the applicable input. In addition, the IVS will notify the user of what error is occurring within the input system. Upon populating applicable values, the IVS will change back to green and read "System Check: Acceptable." This error checking is depicted in *Figure 26.*

5. Independent Inputs – Require a "Yes" or "No" response, however, a "Yes" response does not require additional information (i.e. these inputs do not have corresponding Dependent Inputs). These inputs play a role in the DRPS, but during safety property identification only require the binary response.

Figure 27 schematically presents the workflow of the ASIT system.

INITIAL INPUT VERIFICATION SYSTEM (IIVS)

Framework Rules Functionality	ITEM NAME (Input Data)	Panel P-1 (Background)
PRIMARY INPUTS		
Manual Crushing / Rotating / Slicing Mechanism (YES /NO)	NO	NO REQUIRED INPUTS
Automated Crushing / Rotating / Slicing Mechanism (YES/NO)	NO	NO REQUIRED INPUTS
Suction / Pressure Line (YES / NO)	NO	NO REQUIRED INPUTS
Overhead Equipment (YES / NO)	NO	NO REQUIRED INPUTS
Environmental Air Quality Hazards Present (YES/NO)	NO	NO REQUIRED INPUTS
Environmental Decibel Level Hazard (YES/NO)	NO	NO REQUIRED INPUTS
Hazardous Energy / Live Current Present (YES/NO)	YES	REQUIRE DISCONNECT LOCATION(S), LIMIT SWITCH LOCATION, APPROX. DISCONNECT DISTANCE, VOLTAGE
Manhole or Tank (YES/NO)	NO	NO REQUIRED INPUTS
Hazardous Chemical Production Transmission (YES/NO)	NO	NO REQUIRED INPUTS
Radiation (YES/NO)	NO	NO REQUIRED INPUTS
Heat / Cold Producing Asset (YES/NO)	NO	NO REQUIRED INPUTS
Maintenance Requires Lift System (YES/NO)	NO	NO REQUIRED INPUTS
INDEPENDENT INPUTS		
Located on Roof / Deck (YES/NO)	NO	NO OUTPUT
Outdoor Environment (YES/NO)	NO	NO OUTPUT
Located at a Ledge / Hole (YES/NO)	NO	NO OUTPUT
Exahust Producing Asset (YES /NO)	NO	NO OUTPUT
DEPENDENT INPUTS		
Disconnect Mechanism Location (Manual Only)		
Limit Switch Location (Where In Equipment)		
Harmful Force (Y/N)		
Disconnect Location (Panel Number)		
Secondary Feed Location (Panel Number or None)		
Approximate Disconnect Distance (in feet)		
Valve Location (Valve Number)		
Secondary Valve Location (Valve Number or None)		
Line Size (in inches)		
Approximate Valve Location Distance (in feet)		
Harmful Temperature (Yes/No)		
Maintenance Working Height (in feet)		
Weight (in pounds)		
Support Structure Type (Platform, Threaded Rod, Etc.)		
Lead Present (Yes/No)		
Oxygen Deficient or Enriched Carbon Monoxide Environment (Yes/No)		
Chemical No. 1 Present		
Chemical No. 2 Present (Harmful Chemical or None)		
Chemical No. 3 Present (Harmful Chemical or None)		
Particulate Present (Yes/No)		
Aesbestos Present (Yes/No)		
PCBs Present (Yes/No)		
Environmental Decibel Level (in dBA)		
Voltage (in volts)		
Flooding Potential Exists (Yes/No)		
Milliseiverts of Radiation		
Chemical Storage (YES or None)		

INPUT VERIFICATION SYSTEM

Input	Result
MANUAL EQUIP / DISCONNECT	SYSTEM CHECK: ACCEPTABLE
MANUAL EQUIP / HARMFUL FORCE	SYSTEM CHECK: ACCEPTABLE
AUTOMATED EQUIP / DISCONNECT	SYSTEM CHECK: ACCEPTABLE
AUTOMATED EQUIP / 2nd FEED	SYSTEM CHECK: ACCEPTABLE
AUTOMATED EQUIP / LIMIT SWITCH	SYSTEM CHECK: ACCEPTABLE
AUTOMATED EQUIP / DISTANCE	SYSTEM CHECK: ACCEPTABLE
AUTOMATED EQUIP / HARMFUL FORCE	SYSTEM CHECK: ACCEPTABLE
SUCTION-PRESSURE LINE / VALVE LOCATION	SYSTEM CHECK: ACCEPTABLE
SUCTION-PRESSURE LINE / 2nd VALVE	SYSTEM CHECK: ACCEPTABLE
SUCTION-PRESSURE LINE / HARMFUL FORCE	SYSTEM CHECK: ACCEPTABLE
SUCTION-PRESSURE LINE / VALVE DISTANCE	SYSTEM CHECK: ACCEPTABLE
SUCTION-PRESSURE LINE / LINE SIZE	SYSTEM CHECK: ACCEPTABLE
SUCTION-PRESSURE LINE / TEMP	SYSTEM CHECK: ACCEPTABLE
OVERHEAD EQUIP / MAINTENANCE ELEV	SYSTEM CHECK: ACCEPTABLE
OVERHEAD EQUIP / WEIGHT	SYSTEM CHECK: ACCEPTABLE
OVERHEAD EQUIP / SUPPORT STRUCTURE TYPE	SYSTEM CHECK: ACCEPTABLE
ENV AIR QUALITY / LEAD PAINT	SYSTEM CHECK: ACCEPTABLE
ENV AIR QUALITY / O-CO ENV	SYSTEM CHECK: ACCEPTABLE
ENV AIR QUALITY / CHEM NO. 1	SYSTEM CHECK: ACCEPTABLE
ENV AIR QUALITY / CHEM NO. 2	SYSTEM CHECK: ACCEPTABLE
ENV AIR QUALITY / CHEM NO. 3	SYSTEM CHECK: ACCEPTABLE
ENV AIR QUALITY / PARTICULATE	SYSTEM CHECK: ACCEPTABLE
ENV AIR QUALITY / AESBESTOS	SYSTEM CHECK: ACCEPTABLE
ENV AIR QUALITY / PCB	SYSTEM CHECK: ACCEPTABLE
ENV DECIBEL LEVEL / HEARING PROTECTION	SYSTEM CHECK: ACCEPTABLE
HAZARDOUS ENERGY / VOLTS	ERROR: IDENTIFY VOLTAGE
HAZARDOUS ENERGY / DISCONNECT	ERROR: PRESENT A DISCONNECT LOCATION
HAZARDOUS ENERGY / 2nd FEED	ERROR: PRESENT A SECONDARY FEED
HAZARDOUS ENERGY / DISTANCE	ERROR: PRESENT AN APPROX DISCONNECT DISTANCE
MANHOLE - TANK / FLOOD	SYSTEM CHECK: ACCEPTABLE
MANHOLE - TANK / CHEMICAL	SYSTEM CHECK: ACCEPTABLE
MANHOLE - TANK / VALVE DISTANCE	SYSTEM CHECK: ACCEPTABLE
MANHOLE - TANK / VALVE	SYSTEM CHECK: ACCEPTABLE
MANHOLE - TANK / 2nd VALVE	SYSTEM CHECK: ACCEPTABLE
MANHOLE - TANK / TEMP	SYSTEM CHECK: ACCEPTABLE
HAZ CHEM PRODUCTION / CHEM NO. 1	SYSTEM CHECK: ACCEPTABLE
HAZ CHEM PRODUCTION / CHEM NO. 2	SYSTEM CHECK: ACCEPTABLE
HAZ CHEM PRODUCTION / CHEM NO. 3	SYSTEM CHECK: ACCEPTABLE
MRLS / WORKING HEIGHT	SYSTEM CHECK: ACCEPTABLE
ROOF - DECK / OUTDOOR	SYSTEM CHECK: ACCEPTABLE
HARMFUL RADIATION	SYSTEM CHECK: ACCEPTABLE
CHEMICAL STORAGE	SYSTEM CHECK: ACCEPTABLE
HEAT / COLD - TEMP	SYSTEM CHECK: ACCEPTABLE
CHEMICAL STORAGE - CHEMICALS	SYSTEM CHECK: ACCEPTABLE

Figure 26: Dependent Inputs Requiring Values
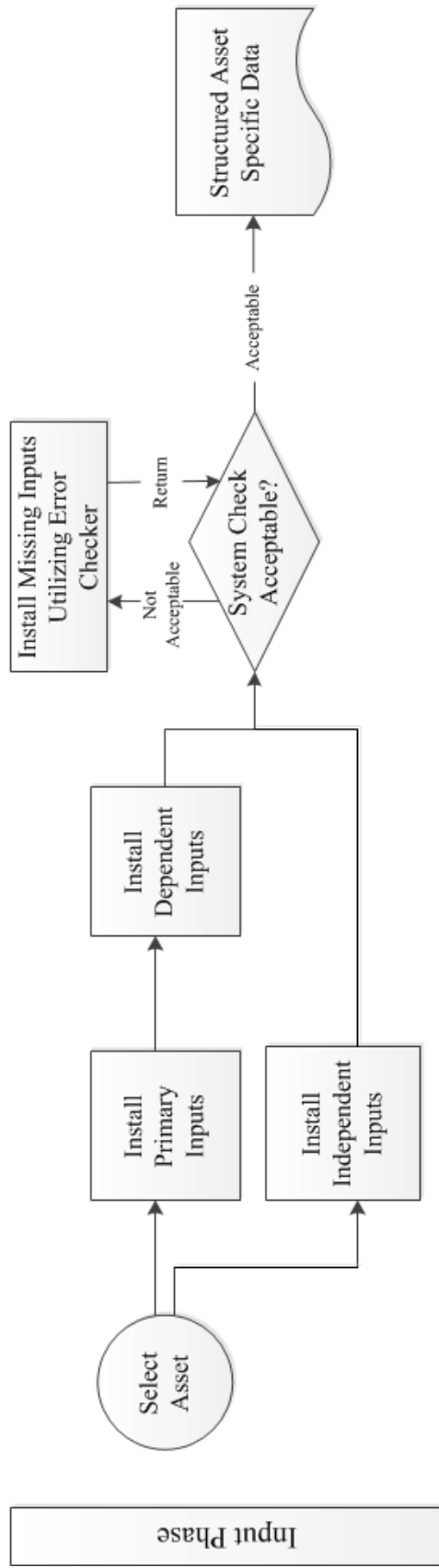
Figure 27: Flow Diagram of ASIT Functionality

Input Phase

Select Asset

Install Primary Inputs

Install Independent Inputs

Install Dependent Inputs

Install Missing Inputs Utilizing Error Checker

System Check Acceptable?

Not Acceptable

Return

Acceptable

Structured Asset Specific Data

In order to test the ASIT functionality, four diverse assets are run through the system in order to develop standard safety properties for ducts, industrial coal-fired boilers, paper rewinders, and ammonia tanks on an ice rick compressor package. Using known O&M information regarding the asset type and the ASIT, the following *Tables 21-24* present the standardized safety properties for each of the four assets tested.

Table 21: ASIT Developed Safety Properties for `Ducts`

Input Type	Inputs	Value
Primary	Overhead Equipment	<User Input Required>
Dependent	Maintenance Working Height	<User Input Required>
Dependent	Weight	<User Input Required>
Dependent	Support Structure Type	<User Input Required>
Primary	Maintenance Requires Lift System	<User Input Required>
Dependent	Maintenance Working Height	<User Input Required>
Primary	Environmental Decibel Level	<User Input Required>
Dependent	Environmental Decibel Level (in dBA)	<User Input Required>
Primary	Environmental Air Quality	<User Input Required>
Dependent	Asbestos Present	<User Input Required>
Dependent	Particulate Present	<User Input Required>
Independent	Outdoor Environment	<User Input Required>

Table 22: ASIT Developed Safety Properties for `IndustrialCFBoiler`

Input Type	Inputs	Value
Primary	Environmental Air Quality	<User Input Required>
Dependent	Oxygen Deficient/Enriched/CO Env.	<User Input Required>
Dependent	Particulate Present	<User Input Required>
Primary	Environmental Decibel Level	<User Input Required>
Dependent	Environmental Decibel Level (in dBA)	<User Input Required>
Primary	Hazardous Energy/Live Current Present	Yes
Dependent	Disconnect Location	<User Input Required>
Dependent	Secondary Feed Location	<User Input Required>
Dependent	Approximate Disconnect Distance	<User Input Required>
Dependent	Voltage	<User Input Required>

Primary	Manhole / Tank / Confined Space	Yes
Dependent	Valve Location	<User Input Required>
Dependent	Secondary Valve Location	<User Input Required>
Dependent	Approximate Valve Distance	<User Input Required>
Dependent	Harmful Temperature	<User Input Required>
Primary	Heat/Cold Producing Asset	Yes
Dependent	Harmful Temperature	Yes

Table 23: ASIT Developed Safety Properties for `PaperRewinder`

Input Type	Inputs	Value
Primary	Automated Crushing/Rotating/Slicing Mechanism	Yes
Dependent	Limit Switch Location	<User Input Required>
Dependent	Harmful Force	<User Input Required>
Dependent	Disconnect Location	<User Input Required>
Dependent	Secondary Feed	<User Input Required>
Dependent	Approximate Disconnect Distance	<User Input Required>
Primary	Hazardous Energy	Yes
Dependent	Voltage	<User Input Required>
Dependent	Disconnect Location	<User Input Required>
Dependent	Secondary Feed	<User Input Required>
Dependent	Approximate Disconnect Distance	<User Input Required>
Primary	Maintenance Requires Lift System	<User Input Required>
Dependent	Working Height	<User Input Required>

Table 24: ASIT Developed Safety Properties for `AmmoniaTank`

Input Type	Inputs	Value
Primary	Suction/Pressure Lines	Yes
Dependent	Valve Location	<User Input Required>
Dependent	Line Size	<User Input Required>
Dependent	Harmful Force	<User Input Required>
Dependent	Secondary Valve Location	<User Input Required>
Dependent	Approximate Valve Location Distance	<User Input Required>

Primary	Environmental Air Quality	Yes
Dependent	Chemical No. 1 Present	Liquid Anhydrous Ammonia
Dependent	Chemical No. 2 Present	<User Input Required>
Primary	Environmental Decibel Level Hazard	<User Input Required>
Dependent	Environmental Decibel Level	<User Input Required>
Primary	Manhole / Tank / Confined Space	Yes
Dependent	Valve Location	<User Input Required>
Dependent	Secondary Valve Location	<User Input Required>
Dependent	Harmful Temperature	<User Input Required>
Dependent	Approximate Valve Location Distance	<User Input Required>
Dependent	Chemical Storage	<User Input Required>
Primary	Hazardous Chemical Production/Transmission	Yes
Dependent	Chemical No. 1 Present	Liquid Anhydrous Ammonia
Primary	Heat / Cold Producing Asset	Yes
Dependent	Harmful Temperature	<User Input Required>
Primary	Overhead Equipment	<User Input Required>
Dependent	Maintenance Working Height	<User Input Required>
Dependent	Weight	<User Input Required>
Dependent	Support Structure Type	<User Input Required>
Primary	Maintenance Requires Lift System	<User Input Required>
Dependent	Maintenance Working Height	<User Input Required>
Independent	Outdoor Environment	<User Input Required>

In *Chapter 7 System Architecture Validation*, the developed standardized safety properties are validated based on specific FM test cases. Utilizing the particulars presented in each test case (i.e. environment, asset location, actor, etc.), values are assigned to the asset and comprehensive safety information is available for the DRPS to process.

As more assets utilize the ASIT for safety property identification, an expanding list of assets are available to design, construction, and FM users for data loading.

For each asset group in any project, the standardized safety properties must be stored by the design/construction professionals within one of two repositories. The properties can be input into a native

model (e.g. the mechanical model developed by the mechanical subcontractor), or the information can remain within the ASIT spreadsheet. As an Excel spreadsheet the properties and values stored in the ASIT can be easily copied over in order to execute a data transfer as presented in *Section 5.6 Data Transfer Mechanism for BIM-Based Framework* of this chapter. Regardless of the method of storage, transferring the safety data from the design and construction phase to the FM phase is challenge that requires resolution in order for the BIM-based Framework to function properly. The next section will cover Phase II – Data Transfer, presenting the challenges of data transfer, the current market solutions, and the transfer mechanism this research utilizes.

5.2. Phase II – Data Transfer

Upon completion of Phase I, applicable safety data needs to be transferred into an Appended BIM Model as presented in *Figure 24*. In an effort to continuously streamline the process of data transfer, a significant amount of research and development has been placed on the utilization of building information models as O&M data storage repositories. Utilizing BIM to store O&M data throughout the lifecycle of the project allows for an Owner to obtain a comprehensive model at the completion of the project. However, this process of BIM data transference is still in its infancy and although great strides have been made, many handover issues still exist (Cleveland 2014). This section will explore the use of building information models as a data transference tool for handover of applicable data to be used during the facilities management phase.

5.2.1. Data Handover Challenges

The transfer of data from the design and construction phases to the facility management phase has remained greatly unchanged for years. Hard copy/electronic O&M manuals, file sharing, and project management hubs, is currently the industry standard. The handover process of information necessary for facility management (e.g. as-built drawings, operations and maintenance manuals, parts list, etc.) continues to deliver such information using a combination of paper printed documents and digital versions of printed documents. This combination of paper-based and digital-based formats have proved unsuitable for the use, maintenance, and management of such information. The majority of the information delivered is still held in documents that do not have a formal structure, making it difficult and time consuming for direct input and interpretation by the computerized facility management system. Those who need to utilize the information provided must go through the additional step of reading the documents, synthesizing and extracting the needed information, and transforming the data into a structured format before inputting the information into the FM system.

Moreover, design and construction documents are not typically turned over to the FM staff until the end of the construction phase. Waiting until the completion of the construction phase / project handover to deliver the needed information, in a largely unstructured format, results in several problems. Mainly, requiring FM staff to recreate and assemble information that has been developed by others, resulting in a slowed handover process, a reduction in the ability to find all the necessary information, and an increased chance of errors and omissions through the time-constrained transcription process.

In addition, issues associated with the current approach of information transfer is the suitability of the information format for later use during operations and maintenance. Fallon and Palmer (2006) defined four major categories of information forms and formats as shown in *Figure 28*. Information is either structured or unstructured. Both can be proprietary or standard.
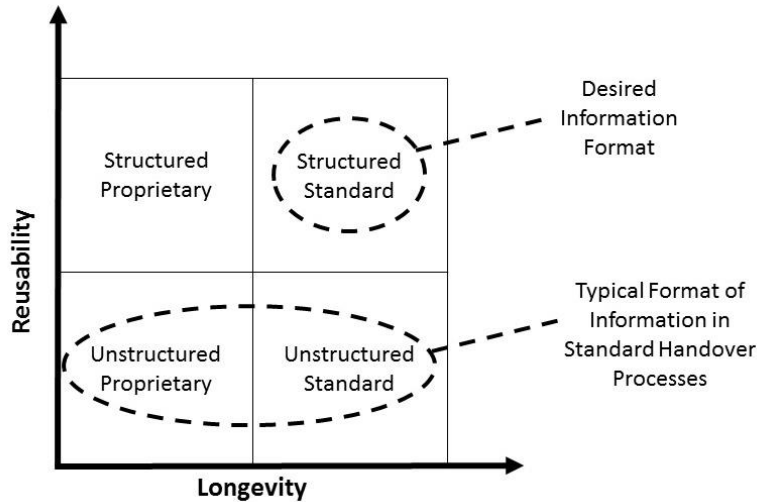
Figure 28: Longevity and Reusability of Information Forms and Formats (adopted from Fallon and Palmer, 2006)

"Structured data" can be accessed and manipulated directly by computer programs without human intervention and is the preferred form to be used in downstream automated processes or when regular updates are required. This form allows for automated—and therefore cost effective—search, retrieval, and update, while maintaining the intelligent information content. Structured information may be quantitative, descriptive, or graphical. There are a number of proprietary structured data models. Examples of structured data formats include information fields defined by the Construction Operation Building Information Exchange (COBie) (East 2007).

"Unstructured Data" is any data that cannot be machine-interpreted, requiring manually intensive interpretation and transcription by the facility staff. Examples include electronic images and electronic .pdf

documents. This form of information is suitable for read only access but unsuitable for an automated framework.

Proprietary formats, also referred to as "native" formats, are created by and are the property of specific software vendors such as CAD programs. Longevity of such formats is sensitive to changes and modifications made by the vendor or discontinuation of the product, rendering the proprietary data unusable.

Standard formats include "Ad hoc" standards or "Formal" standards. "Ad hoc" standards refer to proprietary formats that have been made publically available and are supported by multiple vendors with published specifications. This assures data longevity. Examples include DXF and PDF. "Formal" standards are supported and maintained by official standards organizations such as the Industry Foundation Classed (IFC) maintained by the Building Smart Alliance (National Institute of Building Sciences buildingSMART alliance 2014). In addition to longevity of data stored in this format, it is also more flexible and useful given the format is typically developed through a consensus process.

The majority of the information submitted at handover is unstructured, with some being proprietary, and others standard. This is represented by the two lower left and right quadrants in *Figure 29*. The most efficient format for the purpose of supporting maintenance and operations is structured and standard information. As shown in the top right quadrant of *Figure 29*. Utilizing a standard and structured format greatly mitigates the need to identify, synthesize, and transform the data.

Within the construction industry and amongst facility owners, there is an interest in the utilization of BIM during the FM phase (Becerick-Gerber et al. 2012). The use of BIM as a repository of information is an intuitive step in the evolution of the submittal and O&M process, however the usage of BIM for data transference continues to be rare. The minimal use of BIM as a data transference tool can be attributed to a number of issues. Issues such as model updates, a shortage of BIM skills by FM staff, a lack of collaboration between project and end user stakeholders, contract and legal framework, and interoperability, all contribute to the low utilization of BIM for FM (Becerick-Gerber et al. 2012; East and Brodt 2007; Kelly et al. 2013; Teicholz 2013).

Arguably, the most complex issue faced by project teams, and where a significant amount of research has taken place, is interoperability. Within any project, a number of software may be utilized to design the facility, plan the work, store and exchange the information, and execute FM tasks. This creates a mismatch

of file extensions and proprietary systems that cannot communicate together (Cleveland 2014). Recently, a significant push has been made to incorporate operations and maintenance information into BIM models for facilities maintenance and the linking to FM software. Through the use of BIM interoperability, virtual databases, and add-ons such as COBie, an improvement in O&M storage and retrieval has been achieved to some extent; however, these systems are still not evolved enough to handle all the interoperability. Due to the remaining inefficiencies within the system interoperability, a number of current market solutions have been developed to work-around the issues.

5.2.2. BIM-FM Data Transfer Current Market Solutions

The industry is quite aware of the handover issues and a great deal of research and development has been done in order to mitigate the problems. To date, five broad strategies for data handover exist in order to circumvent current market deficiencies – hard entry, interoperability, middleware, Open Database Connectivity (ODBC), and Application Program Interface (API). The decision to utilize one or more of these strategies, independently or in tandem, is based on a number of factors including existing hardware and software infrastructure, worker training, budget, and user system goals. A greater explanation of each strategy are as follows:

1. Hard Entry – Utilizes attribute and value data inputs. Inputs can be stored in a 3D model or non-model format (i.e. Microsoft Excel).
2. Interoperability – Utilizes software compatibility to transfer relevant information from the native/design file to a different software.
3. Middleware – A compatibility "bridge" that allows for non-interoperable software applications to transfer information (i.e. EcoDomus).
4. Open Database Connectivity (ODBC) – An open standard application for accessing an existing database.
5. Application Program Interface (API) – Sends a programming request to a data source with instructions on how to develop a response, and returns the response.

Often, in order to effectively execute data handover, two or more strategies may be utilized in tandem. Although handover issues are complex and current market systems remain imperfect, many problems can be circumvented with proper planning. Utilizing data exchange frameworks, analysis, and modeling, researchers and developers are actively working to synthesize and seamlessly bridge the gap between design, construction, and FM.

This section reviews three real life examples that utilized data transference and data storage in order to utilize BIM for FM. All of the examples below were executed in order to transfer O&M information in lieu of the safety information that is transferred within the proposed safety framework. Although the variation on data type exists, the processes/procedures employed are still relevant. This section will not present all the possible methods or software combinations and is not intended to present a comprehensive list of all BIM-FM examples, rather it is intended to show that data transference is possible if the appropriate planning takes place. It should be noted that although these instances would be considered successful data transference examples, each case identified limitations and issues associated with the transfer.

The examples presented here utilize summaries and schematic graphics to present data transference. Schematic graphics are intended to present a general flow of data between phases and software. The following examples all utilize Autodesk Revit in some capacity as a design software and/or O&M information repository. This circumstance is a reflection of the software popularity, not an inclusion criteria of this section.

5.2.2.1.   Case 1: Using Hard Data Entry, Interoperability, & Middleware [EcoDomus] for BIM-FM Data Exchange

The USC School of Cinematic Arts initiated a project in 2007 requiring the construction of six buildings in three phases (Teicholz 2013). BIM was utilized for architectural, structural, and MEP disciplines and the implementation of BIM-FM was required from the start of the project. The USC case study is unique in the fact that as the phases progressed, so too did the requirements for BIM-FM implementation. This case presents a project team that evolved along with the technologies and transference limitations. *Figure 29* graphically presents the data transference path for the USC Case Study.
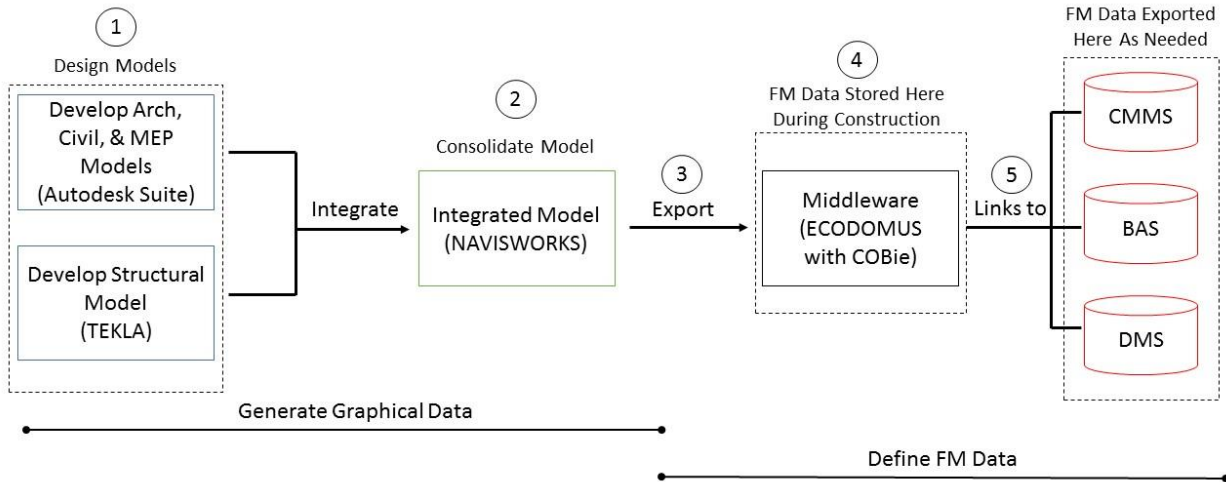
Figure 29: Data Transference Path for USC Case Study

The following presents the flow of data utilizing the numbers presented within *Figure 29*.

1. Architecture, MEP, Civil, and some structural models were created in the Autodesk suite, while the structural engineer utilized Tekla for structural design.

2. The various models were appended into Navisworks to create a comprehensive model and utilize tools such as clash detective for trade coordination. The data being transferred at this point is largely graphical.

3. The comprehensive model along with some FM applicable data was exported to EcoDomus, a middleware software (EcoDomus Inc. 2016).

4. EcoDomus was the primary repository for FM applicable information, as well as the mechanism for transferring data to USC's three online based FM software (CMMS, BAS, and DMS). Much of the data placed into EcoDomus was hard entered into the system or transferred from models via COBie.

5. EcoDomus software also maintained direct links to the online based FM software for easy reference.

As previously mentioned, the project team was aware of the requirements for implementing BIM-FM, but a detailed understanding of what that entailed continued to evolve along with the project. Aside from these planning issues, a few software limitations were identified within this case study. These limitations are presented below.

- At the time of this case study, direct transference could not be executed between the BIM authoring tools (Revit & Navisworks) to the CMMS System. This required the use of EcoDomus, as a true middleware, for items created in Revit that are better suited to be stored in the CMMS System (i.e. component schedules).
- Not all subs maintained a Revit license and therefore the use of 3D models during the construction phase needed to be exported as 3D DWGs and imported into compatible software.
- The use of COBie wasn't implemented until Phase 3 (the final phase) and therefore a definition of what data was needed to be transferred and how that data is stored was vague and disorganized leading up to that point.

This case study presents a number of complex software and planning issues. In spite of that fact, it stands as an excellent example of problem mitigation and team collaboration. This case successfully transferred and organized significant amounts of data utilizing software with minimal interoperability. The use of middleware (EcoDomus) played a large role in this implementation, as a data storage and transference mechanism. As interoperability continues to evolve between FM software and design/coordination software, the cost and software requirements for BIM-FM will likely improve.

5.2.2.2. *Case 2: Using Interoperability & Middleware [FM Interact] for BIM-FM Data Exchange*

Mathworks, Inc. initiated a project in 2005 to add a building to their existing corporate campus (Teicholz 2013). A major factor in the award of the contract was the implementation of BIM. Similar to many owners implementing BIM-FM for the first time, the level of development and requirements for data evolved along with the project. Additionally, many of the subcontractors had various levels of 3D modeling capabilities and therefore a third party BIM consultant was utilized to create a comprehensive Revit model. *Figure 30* presents the data transference path for this project.
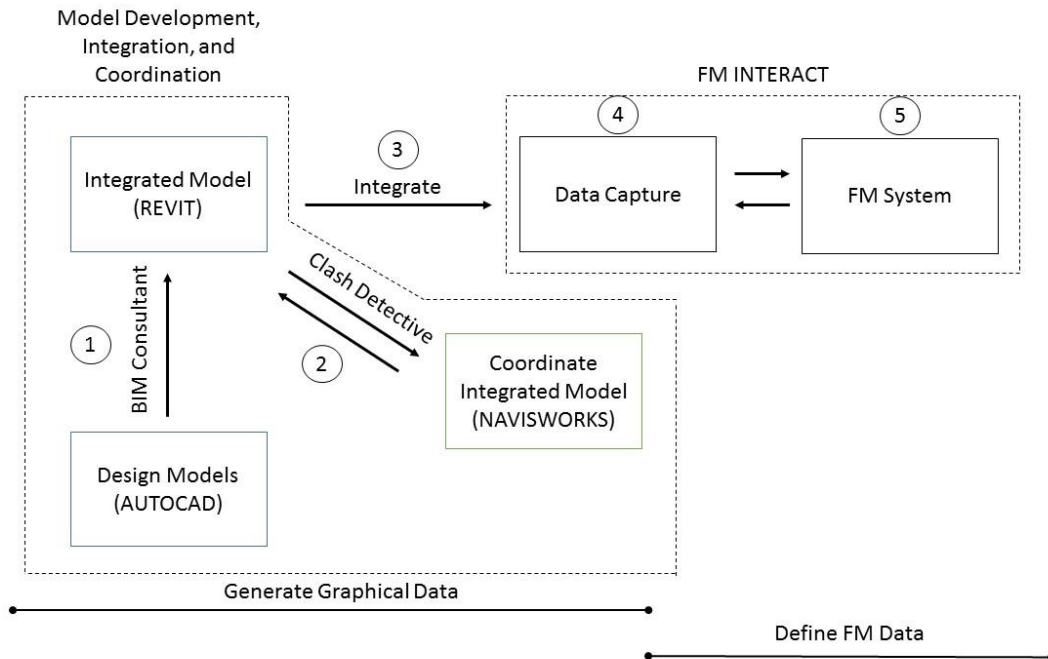
Figure 30: Data Transference Path for MathWorks, Inc. Case Study

The following presents the flow of data utilizing the numbers presented within ***Figure 30***.

1. A BIM Consultant is contracted to develop 2D AutoCAD models, completed by the various project team entities, into a comprehensive 3D model with a link to the existing 3D architecture shell, core, and interiors. Ultimately, a linked Revit model would serve as the final comprehensive model. Data during this phase of the project is almost exclusively graphical.

2. The linked model uses clash detective within Navisworks to prevent conflicts within the 5 linked models.

3. The BIM model, along with the equipment model, properties, and manufacturing information assigned to each piece of equipment, is integrated into FM Interact. These systems have built in interoperability.

4. Once integrated into FM Interact, data can be added or adjusted within the Revit model through the FM Interact add-in.

5. FM staff can access important FM data and model graphics through the FM Interact online portal.

The limitations encountered by the project team are as follows.

- As with many projects involving subcontractors, not all project entities had 3D capabilities. In many cases, implementation of BIM-FM would require the 2D drawings be developed into a 3D

model. In addition to the need to redesign the subcontractor's drawings into a 3D model, which takes time and money, relevant data needs to be added later as the 3D models become available.

- Initially, the owner was not aware of the information they would need for FM. COBie was later used as a reference source, but not as a data transfer mechanism. Without using COBie as a data transfer mechanism, applicable information had to be hard entered into the system.

This case study is a good example of a project that contains varying levels of 3D modeling capabilities. The implementation of BIM-FM requires that all applicable systems be modeled. Without these capabilities, additional considerations and cost allocations are needed to get these systems into the appropriate format.

5.2.2.3.   *Case 3: Using Interoperability and Proprietary Systems [BIMFMM] for BIM-FM Data Exchange*

The BIMFMM Case study is a research project executed by Lin and Su (2013) that utilizes Revit, Navisworks, Open Database Connectivity (ODBC) and a number of subsystems to create the BIMFMM mobile system. The BIMFMM system was designed to allow for FM staff to access real-time BIM models and relevant FM data within the field utilizing a mobile device. *Figure 31* presents the data path of relevant FM information when implementing the BIMFMM system.
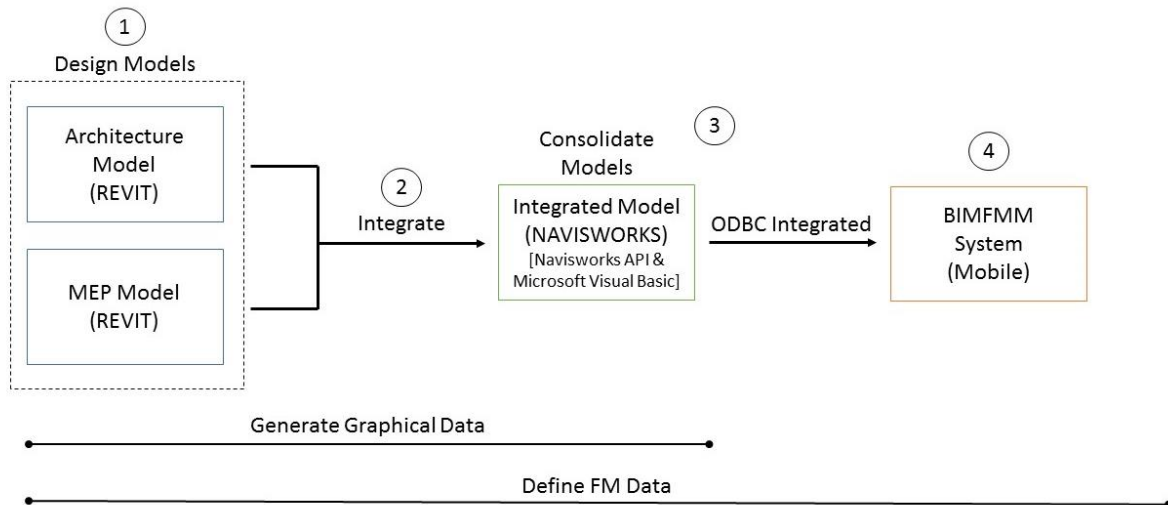
Figure 31: Data Transference Path for BIMFMM Case Study

The following presents the flow of data utilizing the numbers presented within *Figure 31*.

1. Revit Architecture and Revit MEP are utilized for graphical representation of the facility, as well as data storage. The BIM models retained basic description data, parameter-related information, maintenance records, and facility maintenance management reports.
2. Navisworks was utilized as a model integrator to create a comprehensive model.
3. Information integration between the 3D models was achieved by writing code using the Navisworks API and Microsoft Visual Basic.NET programming language. This was done in order to filter the needed information and eliminate the information that was not relevant to the system. Lin and Su (2013) describe the system integration as follows,

   "The BIMFMM system was developed by integrating the 3D BIM models of facilities and maintenance-related information using Navisworks API programming. Open Database Connectivity (ODBC) was utilized to integrate acquired data from different software programs and all maintenance information, such that BIM files can be exported to an ODBC database for connection with the BIMFMM system."
4. The BIMFMM system utilizes a number of internet-based subsystem modules and SQL servers to provide up-to-date information to the mobile devices in the field.

The limitations encountered by the project team are as follows.

- BIM models require constant updates as new equipment is purchased, maintained, or replaced. A system needs to be in place to address these future updates.
- As data is integrated within the BIM models, the NWD files become quite large and cumbersome to download from the SQL servers. Downloads would range from 2-5 minutes.

5.2.3. Summary

As the above examples show, there are multiple ways to circumvent the interoperability issues inherent with varying software applications and various levels of modeling capabilities. To date, there is no single accepted method of data transfer between platforms. By continuously testing new and varying transfer processes, valuable "take-aways" can be identified from a given system based on the success or failure of a transfer mechanism. Through the lessons learned, the data transfer mechanisms employed within the proposed safety framework is developed.

5.2.4. Data Transfer Mechanism for BIM-Based Safety Framework

For this research, two basic input phases are utilized as shown in *Figure 32,* a combined design and construction phase and a FM phase. Through multiple avenues of input, from different contract entities, at

various times in a building's lifecycle, safety relevant information can be stored within the appended Navisworks model.
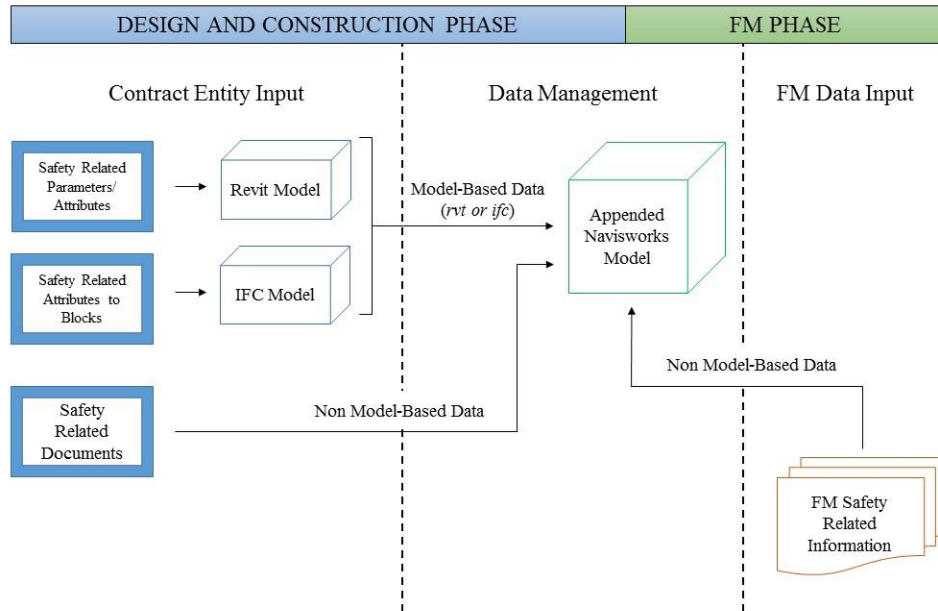

Figure 32: Data Inputs at Three Input Phases

In conjunction with the multi-phased input, this research incorporates two of the four data handover strategies presented in *Section 5.2.2* – Interoperability & Hard Entry.

1. Data Input Through Interoperability:

   Relevant safety information captured by the design/build team (i.e. contract entity input) are captured and stored as parameters or attributes in the native models that are directly imported (i.e. appended) in the federated Navisworks model. This model-based approach for data capture and exchange can use various file formats for the 3D model (populated with the necessary safety relevant data) including .rvt or .ifc formats.

2. Hard Entry:

   Non model-based relevant safety data produced during the design and construction phases or additional needed safety information defined by FM staff during the O&M phase are entered into the appended Navisworks model using direct input, utilizing two data entry tools: Selection Inspector and DataTools.

Figure 32 graphically presents the overall data transfer mechanism employed within the BIM-based safety framework, while Section 5.2.5 provides a proof concept example.

The following is a detailed description of the different steps of *Figure 33*:

1. Relevant safety information generated by various contract entities (designers, consultants, GC, and trades) are captured and stored as parameters/attributes in corresponding native models and appended into a single federated BIM using Navisworks. This model-based approach of data loading a model is efficient, as interoperability between many file extensions and Navisworks allows for a graphical and data transfer.

    When appended in the Navisworks environment, safety data from each model is grouped under a different tab with a system-defined name dependent on the native file format imported.

    In order to make changes to the model-based data, add other non model-based data (generated by contract entities or FM staff), or reorganize and group all data under a single tab with a user defined name, data needs to be exported, modified, then imported back to the federated model. This is achieved using the export and import data manipulation tools from Navisworks: Selection Inspector and DataTools respectively.
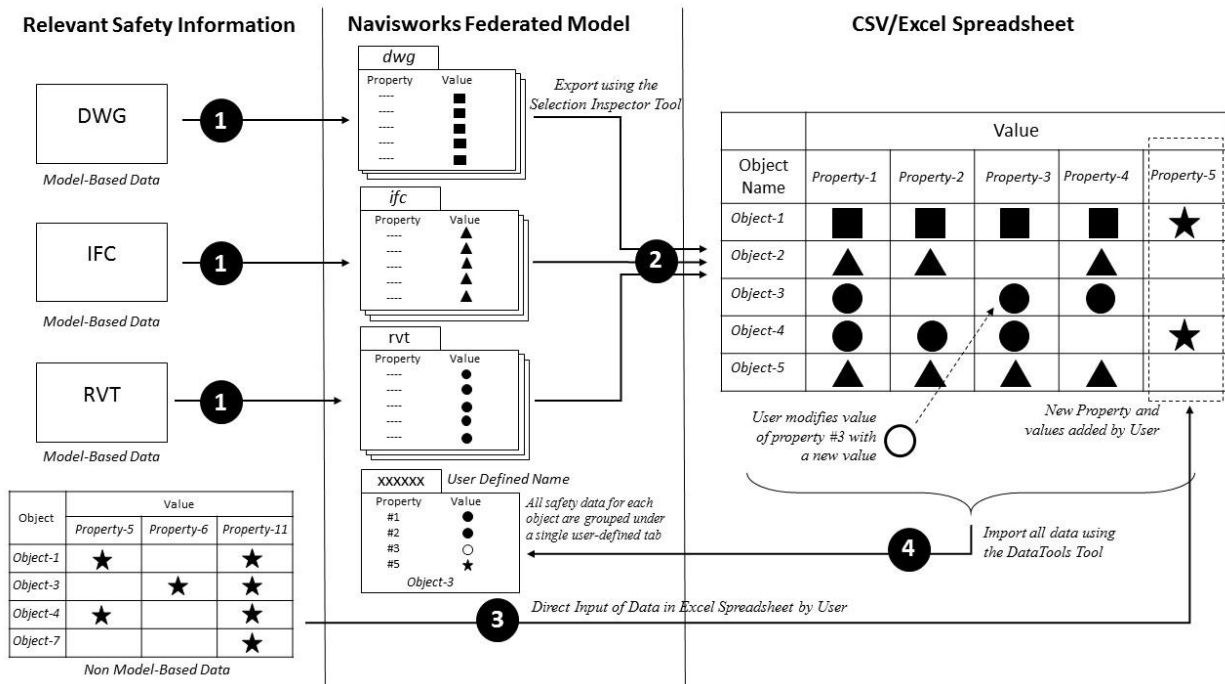
Figure 33: Data Transfer Mechanism within the Safety Framework

2. Using the Selection Inspector tool in Navisworks, appended safety information can be filtered for graphical objects representing the specific equipment targeted for maintenance. Data is the exported to a CSV file and save as an Excel file for modifications. Edits to the data can be manually entered in the Excel spreadsheet

3. Non model-based relevant safety data is directly input by the user in the excel spreadsheet. The user can define new properties (columns) and values for the corresponding objects, or can modify existing properties exported.

4. Once all modifications have been made and new properties and values are added, all data is imported back into the appended Navisworks model using the DataTools function. A user-defined name can be given for the new tab under which all appended safety information will be saved for each graphical object.

   a. Additional safety data can be added directly within Navisworks with the Add New User Data Tab function. This allows for some flexibility of data input as long as the amount of information to be added is small.

Once all data modifications and manipulation are complete, all relevant safety information for the equipment targeted for maintenance can be exported and used to interact with the DRPS.

5.2.5. Data Transfer Mechanism Proof of Concept

This section presents an example of the data transfer mechanism described in *Figure 32.* The proof of concept model, presented in *Figure 34*, is a representative model of a compressor room in an ice skating rink. This model presents a partial compressor package and electrical system with many of the room and compressor elements removed in order to provide clarity to the equipment being utilized within the proof of concept. By presenting a compressor room, a number of hazards can be presented in a single space. Hazards present within an ice skating compressor room include hazardous energy, chemicals (ammonia), automated rotating mechanisms (motors), hazardous decibel levels, overhead equipment, pressurized lines, and heat producing assets. In addition, *Figure 34* presents the equipment that this proof of concept will utilize, a 480V electrical panel, a pump, and a compressor.
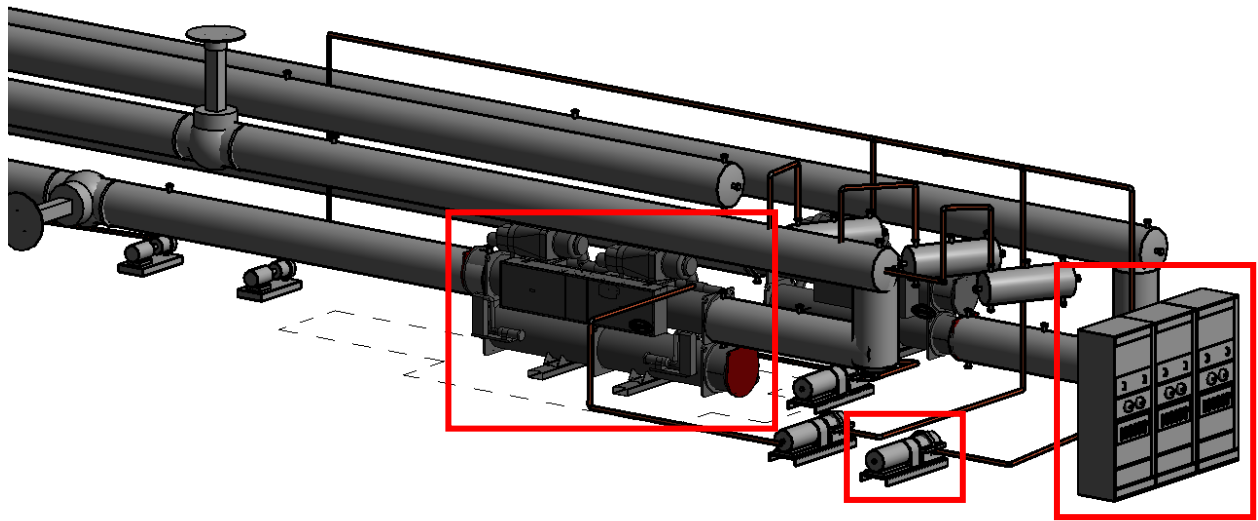
Figure 34: Proof of Concept Model – Compressor Room

In this proof of concept, applicable safety information is loaded into the graphical model through three data transfer mechanisms. First, existing information is input into the native design file developed in Revit 2016. This is executed through the use of shared/project parameters that are assigned to pieces of equipment. This phase simulates the input of data at the design/construction phase, or the "Native BIM-Model" method of transfer presented in *Table 20*. Once shared or project parameters are added to the project and input into the various applicable equipment, the properties and associated values can be manipulated through Schedules/Quantities in Revit 2016. Completion of the "Native BIM-Model" input phase is succeeded by a model export from Revit 2016 into Navisworks Manage 2016. Bringing the design model into Navisworks allows for other models in compatible formats (.rvt, .ifc, .dwg), executed by others, to be brought into a single model space for coordination. Once appended into Navisworks, the safety inputs within the various models are available in the "Properties Tabs" of each piece of equipment. The name of this tab, the

presentation of the safety inputs, and the other properties available within each tab is a function of the native file extension being brought into Navisworks.

Table 25 presents the "Native BIM-Model" inputs utilized in this proof of concept and *Figure 35* presents how the information is presented in Navisworks Manage 2016.

Table 25: Proof of Concept Data Inputs

Equipment	Property	Value
Pump	Electrical Disconnect Location	Panel 103A
	Voltage	460V
	Approx. Disconnect Distance (in feet)	4
	Valve Location	V106
	Approx. Valve Distance (in feet)	8
	Heat Producing Asset	Caution - Hot
Electrical Panel	Voltage	480V/3-0 VA
	Electrical Disconnect Location	Local
	Approx. Disconnect Distance (in feet)	0
Compressor	Voltage	480V/3ph/60Hz
	Electrical Disconnect Location	Panel 103B
	Approx. Disconnect Distance (in feet)	12
	Automated Rotation	Yes
	Heat Producing Asset	Caution - Hot
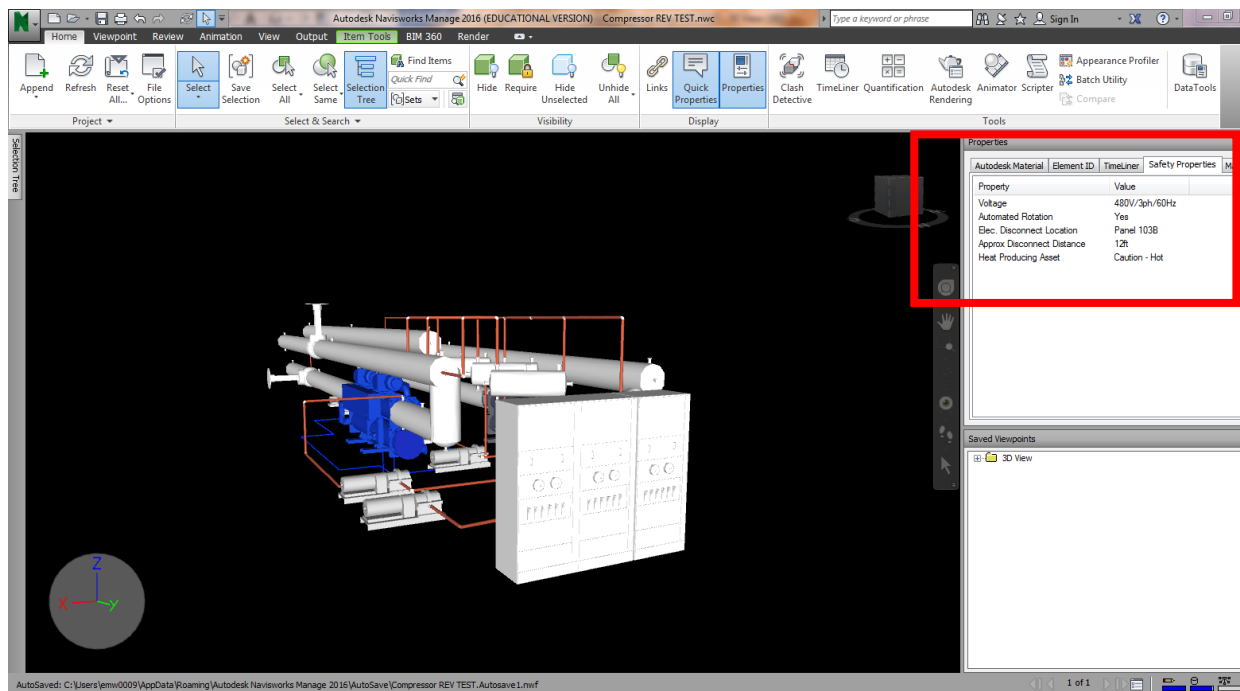
Figure 35: "Native BIM-Model" Inputs in Navisworks Manage 2016

Beyond the "Native BIM-Model" inputs, and as additional safety inputs become available throughout the building's lifecycle, two additional mechanisms of data transfer can be utilized. "Non 3D" and "Direct Input" data inputs are both represented within this phase and are executed using one of two data transfer mechanisms:

1. `Add New User Data Tab` in Navisworks 2016
2. Using `Selection Inspector` and `DataTools` to add data externally in an Excel file and re-import into the model.

Although both data transfer mechanisms result in the same comprehensive, safety data loaded model, the selection of which mechanism is important for efficiency and organization. The use of `Add New User Data Tab` is most efficient when inputting safety inputs for a single, standalone piece of equipment. This scenario is likely when FM staff install a new or updated piece of equipment and the safety inputs need to be added to the graphical element. Using `Selection Inspector` and `DataTools` is utilized when bulk additions or inputs are required for a system. This transfer mechanism is also recommended for most "Non 3D" data inputs as the information is likely in various formats (.doc, .pdf, .xls, etc.) when being submitted to the FM entity.

5.2.5.1.   *Add New User Data Tab*

Once appended into the Navisworks model, additional relevant safety data that was not input into the native model, can be added using `Properties > Add New User Data Tab.` The use of `Add New User Data Tab` is a viable solution for adding information to individual pieces of equipment. For bulk data loading, the utilization of `DataTools` and `Selection Inspector` is recommended. To add a new tab, right click in the properties space and `Add New User Data Tab.` This creates a blank tab titled "User Data." Right clicking in this new tab allows the user to `Rename Tab` and `Insert New Property.` *Figure 36* presents the new safety property input into the compressor package.
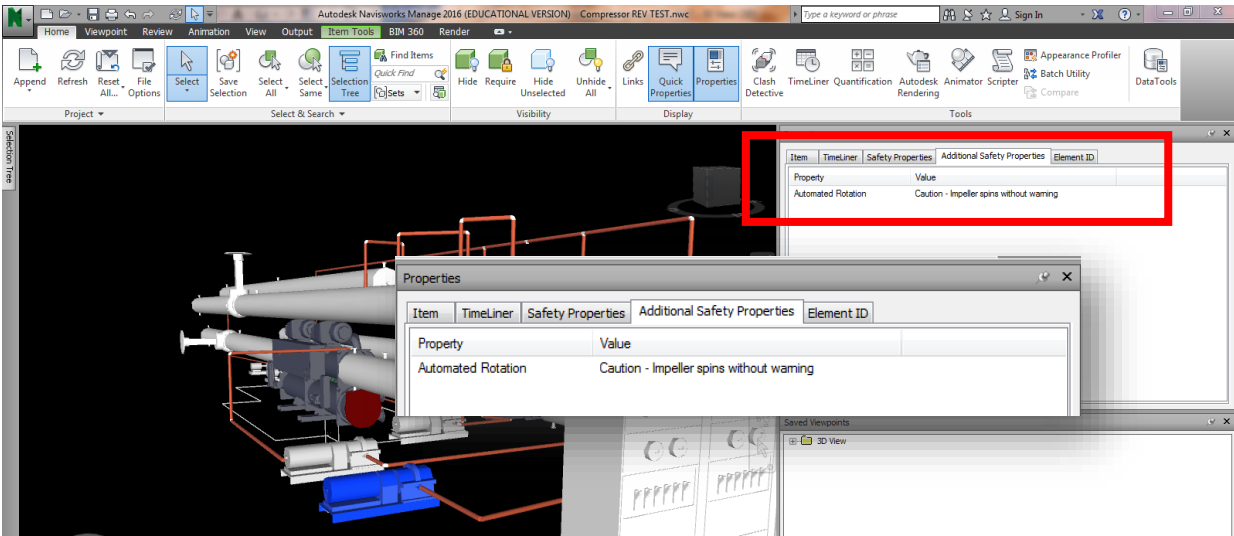
Figure 36: User Defined Safety Property Using "Add New User Data Tab"

5.2.5.2.   *Selection Inspector and Data Tools*

The utilization of `Selection Inspector` and `DataTools` within Navisworks is a viable option to add or adjust multiple properties to a number of graphical elements. This process, although more labor intensive than previously presented processes, allows for data loading of multiple graphics. For this proof of concept model, a typical concern within a compressor room is the significant environmental decibel level that is generated when the compressor system is running. Because of this, hearing protection is required in the compressor room. In order to add this safety property to the environment (room), all pieces of equipment will inherent this safety property. By doing this, the safety property will be presented regardless of the user's equipment selection.

In order to add additional safety properties or adjust existing user defined properties to each piece of equipment, `Selection  Inspector` and `DataTools` are utilized export and re-import safety information. `Selection Inspector` allows for the filtering of specific properties for selected pieces of equipment. This step is important in order to identify which properties a user wants to adjust or place into a new properties tab. `DataTools` is utilized in order to re-import the added/adjusted information back into the graphical model. ***Figure 37*** presents the relevant information that needs to be exported using `Selection Inspector` for this proof of concept, while ***Figure 38*** shows the added information in the exported CSV file. It is important to note that this type of data manipulation requires Microsoft Office 64-bit.

- Property: `Environment Decibel Level(dBA)`

- Value: `105`
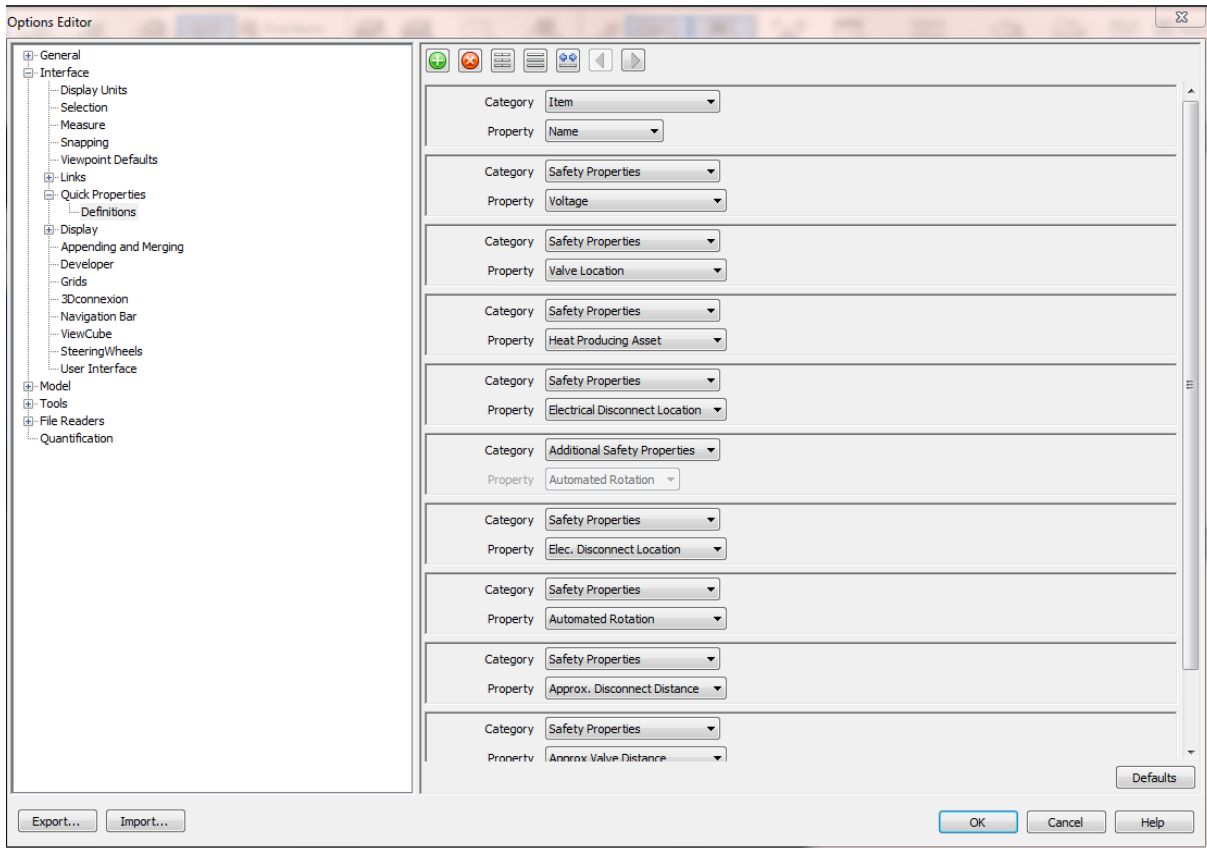
Figure 37: Selection Inspector Export
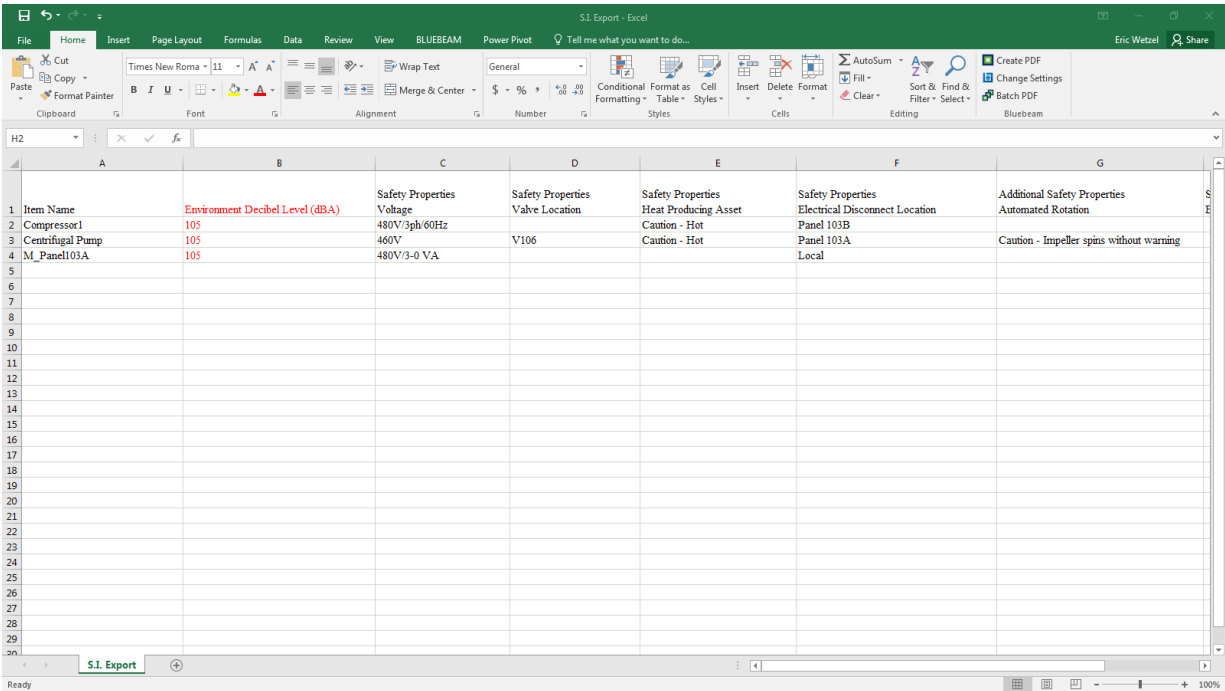
Figure 38: Exported Safety Information and Added "Environment Decibel Level (dBA)" Data

Once the new information is added to the Excel Worksheet, the file needs to be saved as an XLS. This needs to be done in order to reimport using `DataTools`. At this stage, Navisworks should be reopened and Data Tools launched. A new `DataTools` Link needs to be added. *Figure 39* presents the information that must be added in order to map the Excel file to the graphics of the Navisworks file.
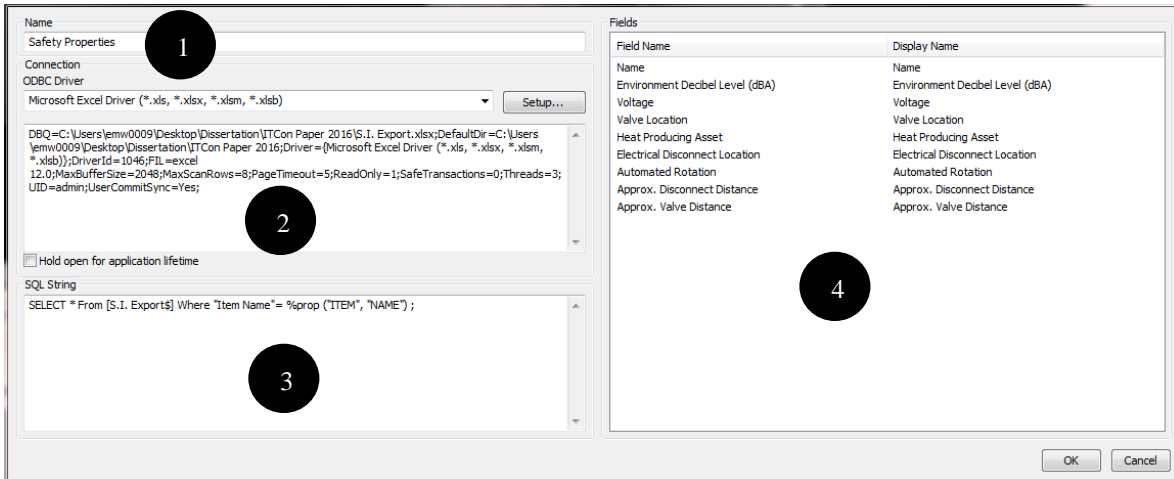

Figure 39: Data Tools Information

1. A name is given to the new `DataTools` Link. This name will become the name of the properties tab in Navisworks that includes all of the properties identified in the "Fields" area.

2. Using an ODBC Driver connection, a link is made between the Excel file and the Navisworks file. Upon selecting the file in `Setup`. The mapping of the two files is automatically generated.

3. An SQL String needs to be written in order to link the information in the Excel file to the applicable graphics in the Navisworks file. This is executed by mapping the specific equipment name, known as "Item Name" in Navisworks, to the "Item Name" column in Excel. The SQL String reads as follows:

```
SELECT * From [S.I. Export$] Where "Item Name"= %prop ("Item", "Name");
```


Sheet Name in Excel   Column Name in Excel to map to Navisworks   Graphic Identifiers in Navisworks in order to map to Excel
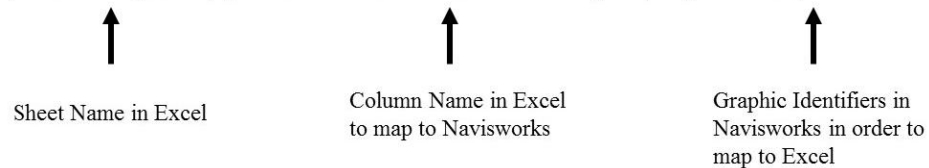
4. User needs to input the `Field Name` they wish to see under the new developed "Safety Properties" tab. For this example, the "Name" of the piece of equipment and the added "Environment Decibel Level" property will be mapped to the graphics. Only properties that have values will be transferred to individual graphics. *Figure 40* presents the added safety properties in the newly developed "Safety Properties" tab for the electrical panel upon the execution of the DataTools process.
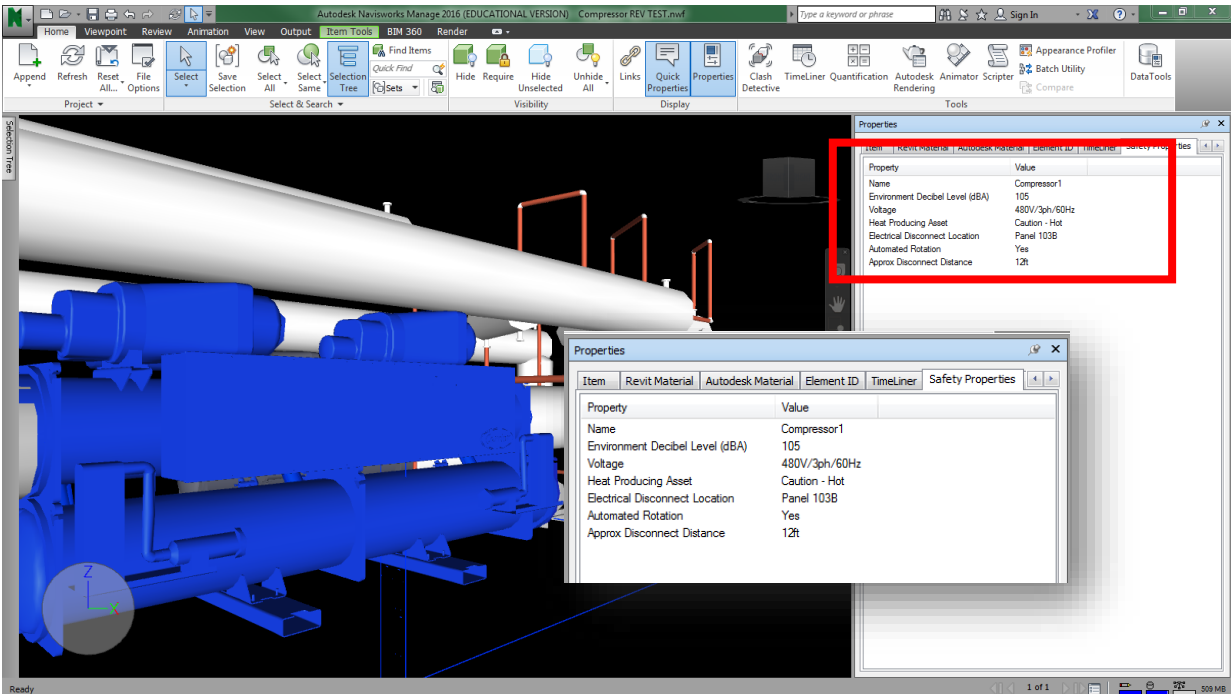
Figure 40: Added Safety Properties Under New "Safety Properties" Tab

This process can be repeated to add or update information. Once all the relevant safety information is stored in the Integrated BIM Model, launching the DRPS adds logic and guides the information exchange of the safety data. As described in Wetzel and Thabet (2015), "Based on the values assigned to the properties, rules and process models guide the information logic and present the information via a graphical user interface (interface).

6. DATA RETRIEVAL AND PROCESSING SYSTEM (DRPS)

Once all the relevant safety information is stored in the Appended BIM Model, launching the DRPS adds logic and guides the information exchange of the safety data. *Figure 41* identifies this final step within the BIM-Based Safety Framework as Phase III.
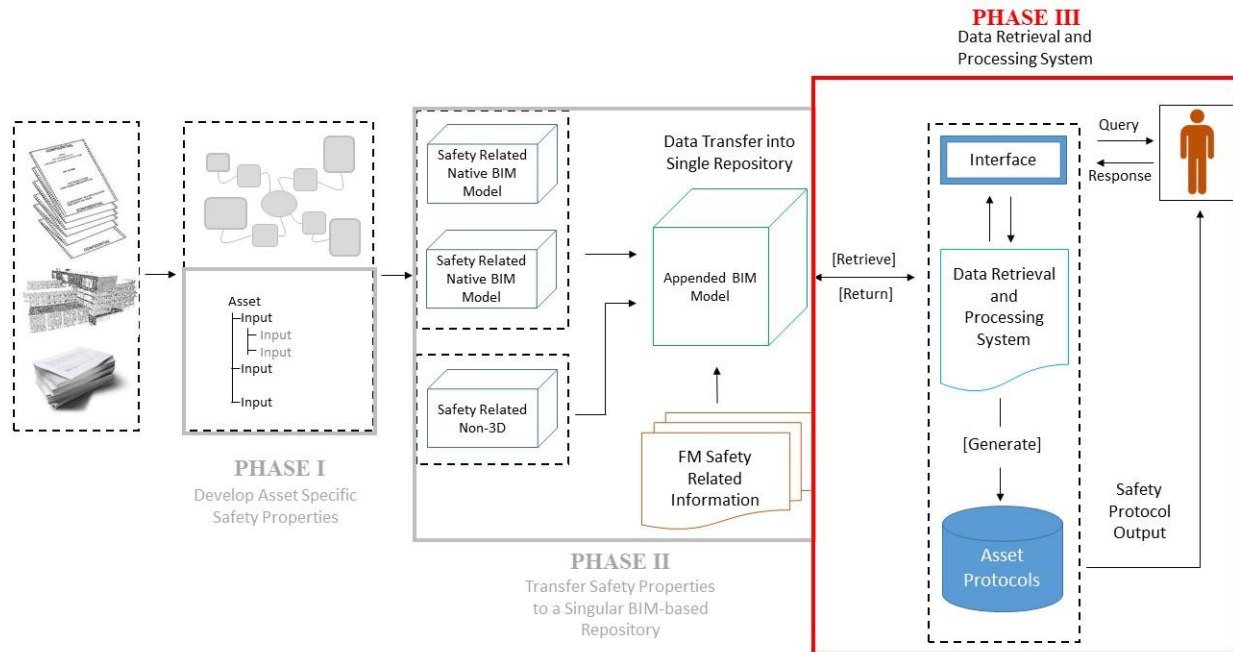

Figure 41: Phase III of the BIM-Based Safety Framework

The DRPS has two primary functions. First, retrieve the asset specific safety inputs and values stored within the Appended BIM Model. Accessing the data is the first step in order to enact the data processing on the returned results. The second function of the DRPS is to recognize FM tasks that require user input and subsequently launch the query system. In order to properly present the safety hazards and appropriate protocols to the FM users, the decision making of the user must be taken into account. Although many of the safety hazards and protocols can be presented to the user based strictly on the asset being maintained or the environment in which the asset resides, the FM user will make decisions that will impact the safety of the FM task. An example of this is the selection of a lift system in order to execute a task at elevation. The protocols regarding work on a ladder differ significantly from working on a man lift. In order to present task-specific safety information to a FM worker, all of the factors regarding the asset, environment, and approach must be known. Other examples of task specific queries are depicted in *Table 26.* This list is non-exhaustive and while some standard queries can be loaded into the system, in a commercial application, the task specific queries within the DRPS would need to be customized to the particular facility.

Table 26: Task Specific Queries Launched by the DRPS (Examples)

Safety Input(s)	DRPS Query	Protocol
Maintenance Requires a Lift System	Identify the lift system utilized for this FM task: <list available lift system>	Lift system specific
Voltage	Yes or No, this FM activity requires exposing live current? <radio button selection>	Lockout/Tagout
Environmental Air Quality Hazards Present	Yes or No, this FM task requires welding? <radio button selection>	Welding in toxic, gaseous, chemical, and/or enriched environments
Maintenance Requires Lift System + Outdoor Environment + Mechanized Lift System Selection	Yes or No, the current wind speed is within the specified safety considerations for this lift system? <radio button selection>	Lift system specific

Retrieving stored asset information, analyzing that information, and ultimately presenting the applicable, task-specific protocols to the FM worker is the primary objective of the DRPS. This chapter will present the system architecture required to execute this objective, validate the system architecture through various FM test cases, and present a proof of concept by presenting the conceptual GUI within the sequence diagrams in the context of a selected test case.

6.1. System Architecture

In order to present the functionality of the DRPS, three platforms are utilized – a product model, a sequence diagram, and a conceptual GUI. A product model uses an object-oriented data structure to formally classify information to support the exchange of data through a mechanism (Eastman 1999). By executing a product model through a UML Class Diagram, a type of "Structural Diagram," a conceptual schema or framework of data can be properly structured and stored (Pilone and Pitman 2005). A sequence diagram, a type of "Behavioral Diagram," presents how objects interact in a particular scenario over a period of time (Visual Paradigm 2016). For this research, a sequence diagram is developed to present how the product model classes interact and the system retrieves the relevant safety information. Finally, a conceptual GUI is utilized in order to present the interface between the user and the DRPS. The use of a conceptual GUI in correlation to the product model and sequence diagram in the context of a test case presents a proof concept.

6.1.1. Product Model and Sequence Diagram Development

The product model (UML class diagram) in this research is developed based on the information obtained through the first two phases of the Six Sigma methodology – Define and Measure. Establishing what safety information is relevant to FM workers and how that information is related, sets the baseline for the product model development. *Figure 42* presents the UML class diagram for the DRPS.
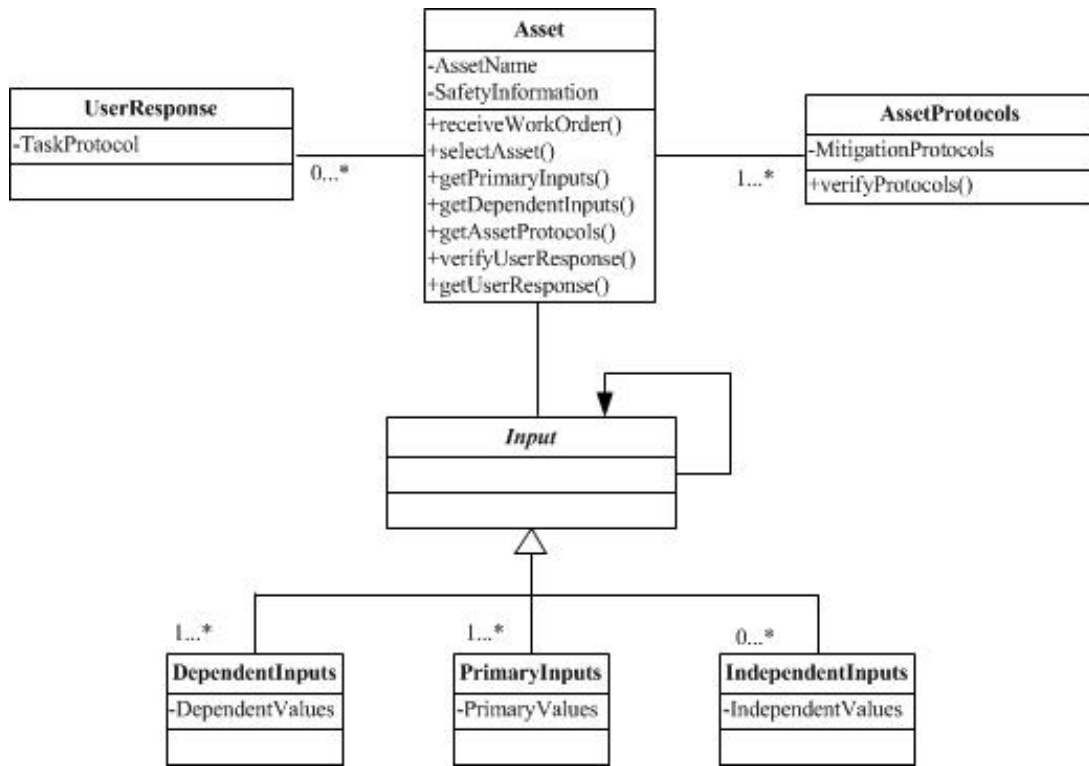

Figure 42: DRPS Product Model

The developed product model uses a single core class and five subclasses in order to execute delivery of safety information. Asset, the core class, is a robust class where the initial event takes place and is required to distribute tasks, obtain the returned information, verify additional user input, and present the comprehensive safety information. DependentInputs, PrimaryInputs, and IndependentInputs, are all dependent classes to the abstract class Input. The Input class is a subclass to Asset and has no operation. The Input subclass holds the properties and values for each stored asset. UserResponse stores the task specific inputs that may or may not return a value. These inputs are presented only when a query system response is required. The final subclass, AssetProtocols, maintains the hazard mitigation techniques for each input.

As shown in the product model, each class serves a function in the system architecture. In order to present how the classes interact within the system over a period of time, a sequence diagram is developed. The sequence diagram (*Figure 43*) graphically depicts the steps that the DRPS utilizes from receipt of an event to the delivery of the safety information.
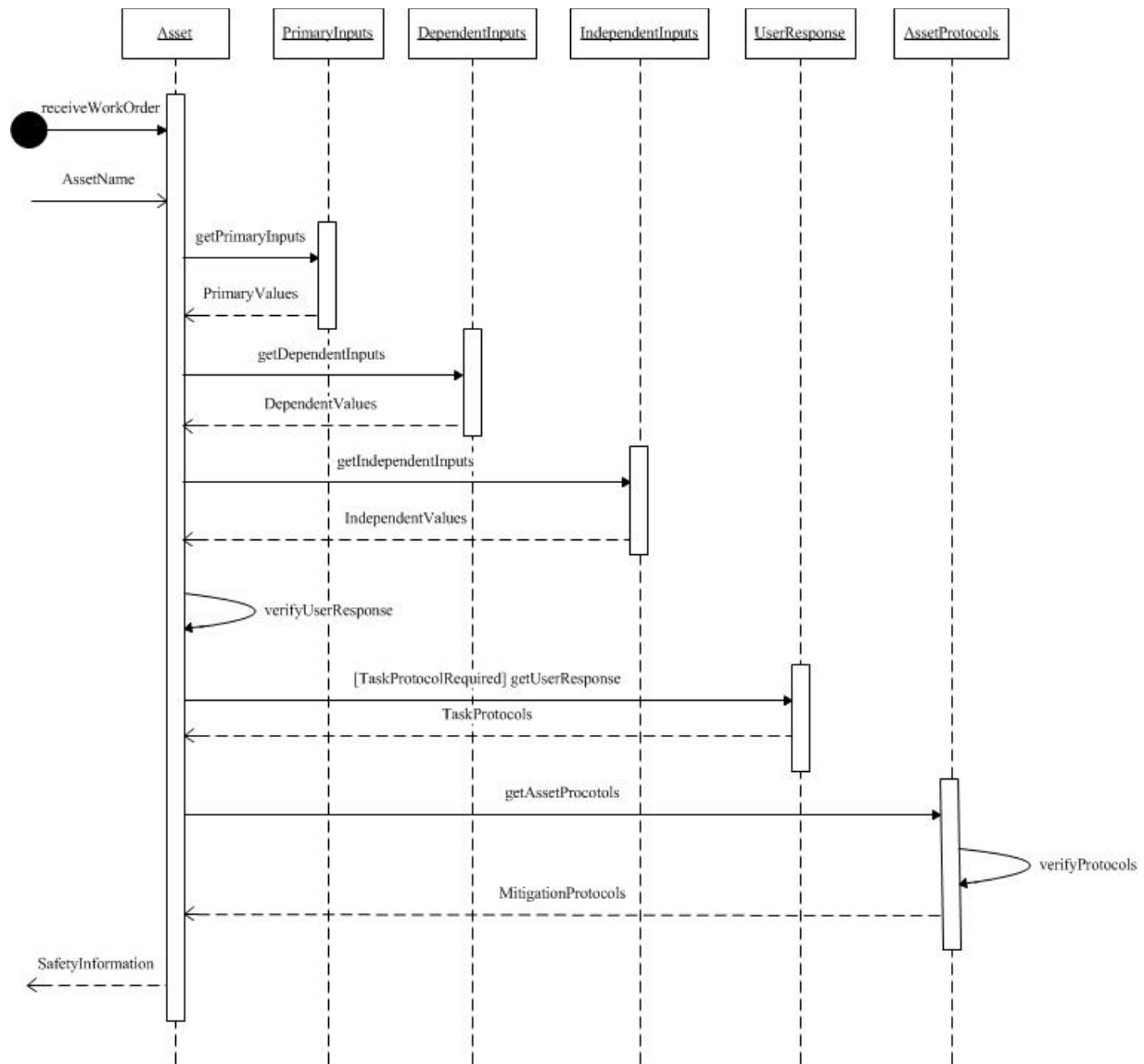

Figure 43: DRPS Sequence Diagram

The initiation event in a FM task is often the receipt of the work order with an asset requiring maintenance. Within the sequence diagram, this event prompts the user to select which `Asset` is requiring maintenance. Upon receipt of the `Asset`, the system can retrieve the stored `PrimaryInputs`,

`DependentInputs,` and `IndepentdentInputs` for that specific asset. Once all the safety inputs are returned, the system will call on itself to `VerifyUserResponse`. By evaluating the returned inputs, the system will check to see if additional task specific information is required by the user. For example, the selection of a lift system. The `UserResponse` is not required in all FM tasks and therefore is guarded by [`TaskProtocolRequired`]. If the specific task does require task specific information from the user, the system will initiate the query system and retrieve the responses. With all of the inputs returned, the system can retrieve the applicable `AssetProtocols`. Before returning the protocols, the system will once again call on itself to evaluate the information through `VerifyProtocols`. This function verifies the retrieved protocols and executes the following tasks if required:

- Eliminate Protocol Redundancies – As shown in *Table 20* a number of Safety Inputs share Safety Protocols (e.g. Hazardous Energy & Automated Crushing/Slicing/Rotating Mechanism). In order to eliminate congestion or confusion in the output to the user, the DRPS will eliminate redundancies of returned protocols and only present the information once.

- Eliminate Non-Applicable Protocols Based on User Response – Each Safety Input has a set of Safety Protocols that should be delivered if a value is available for the DRPS to return. In most cases this functionality works without intervention from the DRPS; however, in some instances a user response will require a decision to be executed by the DRPS in order to present the correct protocol.

For example, the user selects "Ladder" as their lift system. Utilizing a ladder does not require the use of a fall arrest system and therefore this protocol can be eliminated from the returned `MitigationProtocols`. The script for this function is as follows:

```
IF (TaskProtocols == "Ladder") {
      return (MitigationProtocols _.omit(FallArrestSystem/Anchorage)); }

      ELSE {
          return (MitigationProtocols);}
```

The above rule states that if the `TaskProtocols` selected by the user is "Ladder," the system will omit the `FallArrestSystem/Anchorage` protocol. This function is required as a fall arrest system isn't required while utilizing a ladder. With any other `UserResponse` (manlift, scissor lift, platform, etc.) the system will return the full array of `MitigationProtocols` identified by the system.

Once the system verifies the protocols, the `MitigationProtocols` are sent back to the asset and presented as structured `SafetyInformation` for user consumption. The `SafetyInformation` in this research plays an important role in the DRPS system as a mechanism for presenting the protocols to the user; however, the scope of this research excludes the media in which this information is presented. Currently, the system conceptually presents this information as text-based listing of safety hazards and protocols. As shown in Chapter 8, future research may identify a better mechanism to present this information (e.g. videos, images, augmented reality, etc.).

Chapter 7 System Architecture Validation presents the last phase of the Six Sigma methodology, Verify, through a number of mechanisms to test the system functionality.

7. SYSTEM ARCHITECTURE VALIDATION

As with the development of any new process, validation through an existing evaluation mechanism is important. To ensure that the product model design and sequence diagram executed within this research elected to validated the system based on Turkaslan-Bulbul and Akin (2007). This validation step requires that the product model maintain three characteristics:

1. The Scope: the information covered in the data model is capable of representing the attributes of the domain.
2. The Flexibility: the data model is designed to have a modular structure, where new data can be added or exchanged within the system without major edits.
3. The Support: the functional usage of the product model.

The first characteristic, scope, has already been validated through the execution of the Data Validation interviews. As the product model was developed from the validated data points collected within this research, the attributes of the product model are confirmed as domain specific. The flexibility of the product model and sequence diagram will be validated through FM test cases. By back-checking the product model and sequence diagram on various scenarios utilizing multiple safety inputs, nuances to each scenario can be incorporated in order to validate the flexibility of the system. If the product model and sequence diagram is robust enough to not require major edits through all the test cases, the system is validated. Finally, the functional nature of the product model and sequence diagram is validated through the incorporation of the conceptual GUI. By presenting the product model and sequence diagram in the form of a graphical interface, the industrial application or functional usage of the system is presented. Additionally, this step will serve as a proof of concept for the DRPS.

The following test cases are utilized in order to verify that the product model and sequence diagram developed in this research function as intended. Each test case will present a unique FM task and associated hazards. Running the system through multiple scenarios validates the architecture of the system. The test cases utilized in this section are a combination of two fatal accidents from the FACE reports and two typical FM tasks validated by industry experts. The structure of each section is as follows:

1. The task being performed or the accident that occurred.
2. The data loaded ASIT as it would be presented for the specific asset requiring maintenance.
3. Table summarizing the ASIT data load.
4. The sequence diagram with the applicable commands being executed based on the FM test case.

Following the test cases, a proof of concept is presented in *Section 7.4 DRPS Proof of Concept* by incorporating one of the FM test cases with the conceptual graphical user interface.

7.1. FM Test Case No. 1 – FACE Report 9013

A 21-year-old worker died as a result of injuries sustained in a 12-foot fall from a scaffold. The victim was a member of a six-man crew engaged in the removal of asbestos-contaminated insulation from a series of large ducts on the exterior of an electric power generation plant. The victim was removing asbestos insulation from a large outdoor metal duct approximately 14 feet above the ground. The worksite was accessed by tubular metal scaffolding. The victim was working at the 12-foot level of the scaffold. The scaffold was not decked at this level. Instead, the crew had installed a single 2-inch by 12-inch plank across the tubing. The plank extended beyond the tubing on both sides and was not fastened in position to the tubing. Instead, the crew had driven two nails into each end of the plank at 45 degree angles to hold the plank against the tubing while allowing them to slide the plank along the tubing to various areas where they were working. The nails on one end of the plank had loosened sufficiently to slip free from the scaffold. The weight of the victim on the opposite end of the plank caused the plank to rise up in the air, dropping the victim to the ground below.

Based on the above FM test case, values can be assigned to the ASIT identified safety properties for asset group `Ducts`. ***Figure 44*** presents the data load applicable for this specific FM test case. Note: Not all of the necessary safety data presented in the ASIT is available in the FACE Report but has been added in order to present the appropriate data loading for this test case.

INITIAL INPUT VERIFICATION SYSTEM (IIVS)		
	ITEM NAME	**ExteriorDucts**
Framework Rules Functionality	**Input Data**	**Background**
PRIMARY INPUTS		
Manual Crushing / Rotating / Slicing Mechanism (YES / NO)	NO	NO REQUIRED INPUTS
Automated Crushing / Rotating / Slicing Mechanism (YES / NO)	NO	NO REQUIRED INPUTS
Suction / Pressure Line (YES / NO)	NO	NO REQUIRED INPUTS
Overhead Equipment (YES / NO)	YES	REQUIRES MAINTENANCE ELEVATION, WEIGHT, & SUPPORT
Environmental Air Quality Hazards Present (YES/NO)	YES	AIR QUALITY HAZARD TYPE DESIGNATION
Environmental Decibel Level Hazard (YES/NO)	NO	NO REQUIRED INPUTS
Hazardous Energy / Live Current Present (YES/NO)	NO	NO REQUIRED INPUTS
Manhole or Tank (YES/NO)	NO	NO REQUIRED INPUTS
Hazardous Chemical Production Transmission (YES/NO)	NO	NO REQUIRED INPUTS
Radiation (YES/NO)	NO	NO REQUIRED INPUTS
Heat / Cold Producing Asset (YES/NO)	NO	NO REQUIRED INPUTS
Maintenance Requires Lift System (YES/NO)	YES	REQUIRE WORKING HEIGHT
INDEPENDENT INPUTS		
Located on Roof / Deck (YES/NO)	NO	NO OUTPUT
Outdoor Environment (YES/NO)	YES	WEATHER CONDITIONS CONSIDERATIONS
Located at a Ledge / Hole (YES/NO)	NO	NO OUTPUT
Exahust Producing Asset (YES./NO)	NO	NO OUTPUT
DEPENDENT INPUTS		
Disconnect Mechanism Location (Manual Only)		
Limit Switch Location (Where In Equipment)		
Harmful Force (Y/N)		
Disconnect Location (Panel Number)		
Secondary Feed Location (Panel Number or None)		
Approximate Disconnect Distance (in feet)		
Valve Location (Valve Number)		
Secondary Valve Location (Valve Number or None)		
Line Size (in inches)		
Approximate Valve Location Distance (in feet)		
Harmful Temperature (Yes/No)		
Maintenance Working Height (in feet)	14	SENT TO DATA SHEET
Weight (in pounds)	4 lbs/sqft	SENT TO DATA SHEET
Support Structure Type (Platform, Threaded Rod, Etc.)	Unistrut	SENT TO DATA SHEET
Lead Present (Yes/No)	No	SENT TO DATA SHEET
Oxygen Deficient or Enriched / Carbon Monoxide Enviroment (Yes/No)	No	SENT TO DATA SHEET
Chemical No.1 Present	No	SENT TO DATA SHEET
Chemical No. 2 Present (Harmful Chemical or None)	No	SENT TO DATA SHEET
Chemical No. 3 Present (Harmful Chemical or None)	No	SENT TO DATA SHEET
Particulate Present (Yes/No)	No	SENT TO DATA SHEET
Asbestos Present (Yes/No)	Yes	SENT TO DATA SHEET
PCBs Present (Yes/No)	No	SENT TO DATA SHEET
Environmental Decibel Level (in dBA)		
Voltage (in volts)		
Flooding Potential Exists (Yes/No)		
Milliservients of Radiation		
Chemical Storage (YES or None)		

Figure 44: ASIT Data Load for Ducts – FM Test Case No. 1

Table 27 presents the values required for the `Ducts` for this particular test case.

Table 27: Test Case No. 1 Relevant ASIT Data for Exterior `Ducts`

Input Type	Inputs	Value
Primary	Overhead Equipment	Yes
Dependent	Maintenance Working Height	14ft
Dependent	Weight	4 lbs/sqft
Dependent	Support Structure Type	Unistrut
Primary	Maintenance Requires Lift System	Yes
Dependent	Maintenance Working Height	14ft
Primary	Environmental Air Quality	Yes
Dependent	Asbestos Present	Yes
Independent	Outdoor Environment	Yes

Figure 45 outlines the process the DRPS would execute in order to return results to the FM worker prior to executing the FM task.
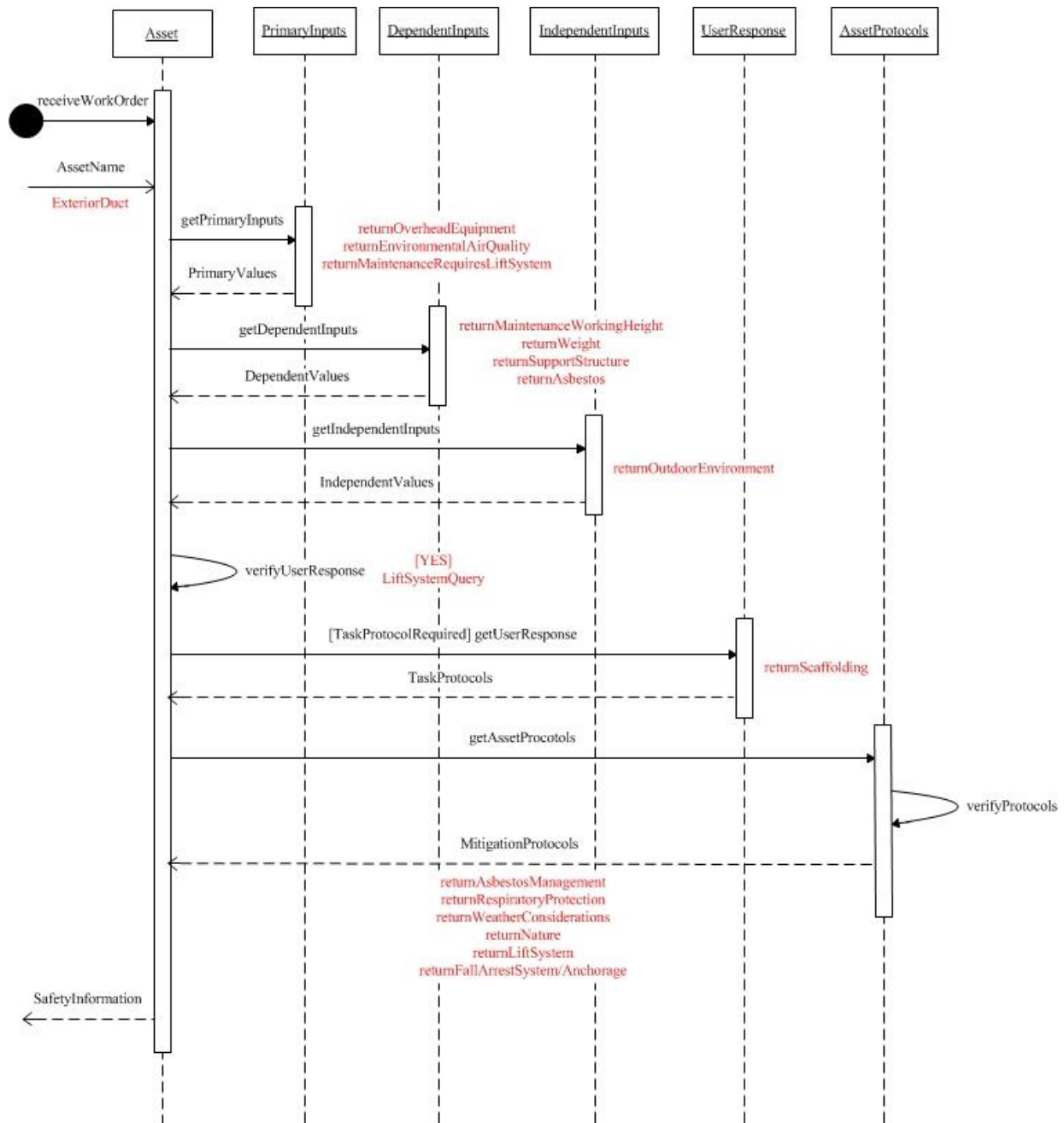
Figure 45: Sequence Diagram for Ducts – FM Test Case No. 1

Upon receiving the work order and launching the DRPS, the system will identify the Asset and execute the getPrimaryInputs, getDependentInputs, and getIndependentInputs command. Executing these commands for the asset requiring maintenance returns the PrimaryValues (OverheadEquipment, EnvironmentalAirQuality, & MaintenanceRequiresLiftSystem), the DependentValues

114

(`MaintenanceWorkingHeight`, `Weight`, `SupportStructure`, & `Asbestos`), and the `IndependentValues` (`OutdoorEnvironment`). Once the DRPS returns all of the applicable values, the system can process the information and verify if a query should be launched. In this scenario, the `MaintenanceRequiresLiftSystem` input has been assigned a value and therefore the system will query the user on which lift system will be utilized. From the FM test case an election of `Scaffolding` is made. With all of the inputs identified, the system can evaluate and return the `MitigationProtocols` for the specific FM task. The protocols being returned in this test case address three hazards:

1. Asbestos
    a. `returnAsbestosManagement`
    b. `returnRespiratoryProtection`
2. Outdoor Environment
    a. `returnWeatherConsiderations`
    b. `returnNature`
3. Falls
    a. `returnLiftSystem` (Scaffolding Protocol)
    b. `returnFallArrestSystem/Anchorage`

7.2. FM Test Case No. 2 – Coal Fired Boiler Preventative Maintenance

The following test case was validated by a Safety Compliance Officer at a university located in the Eastern USA.

An FM worker is tasked with cleaning the fire box of a 7'x7' coal-fired boiler. As the boiler burns coal in order to produce steam, ash and soot lines the interior of the fire box. As ash and soot build up within the boiler, the efficiency of the boiler is reduced. Preventative maintenance protocols require the fire box be cleaned biennially. The boiler requiring maintenance is located within one of the power houses on the campus where a number of motors and tanks create a high decibel level environment. In order to thoroughly clean the boiler fire box the worker must enter the tank which has been identified as a confined space.

Based on the above FM test case, an ASIT can be loaded with the applicable safety information. *Figure 46* presents the data load applicable for this FM test case.

INITIAL INPUT VERIFICATION SYSTEM (IIVS)		
	ITEM NAME	**Boiler1**
Framework Rules Functionality	**Input Data**	**Background**
PRIMARY INPUTS		
Manual Crushing / Rotating / Slicing Mechanism (YES / NO)	NO	NO REQUIRED INPUTS
Automated Crushing / Rotating / Slicing Mechanism (YES / NO)	NO	NO REQUIRED INPUTS
Suction / Pressure Line (YES / NO)	NO	NO REQUIRED INPUTS
Overhead Equipment (YES / NO)	NO	NO REQUIRED INPUTS
Environmental Air Quality Hazards Present (YES/NO)	YES	AIR QUALITY HAZARD TYPE DESIGNATION
Environmental Decibel Level Hazard (YES/NO)	YES	HEARING PROTECTION REQUIRED
Hazardous Energy / Live Current Present (YES/NO)	YES	REQUIRE DISCONNECT LOCATION(S), LIMIT SWITCH LOCATION, APPROX. DISCONNECT DISTANCE, VOLTAGE
Manhole or Tank (YES/NO)	YES	REQUIRE FLOOD/SUBMERGE POTENTIAL, CHEMICAL, VALVE, APPROX VALVE DISTANCE
Hazardous Chemical Production Transmission (YES/NO)	NO	NO REQUIRED INPUTS
Radiation (YES/NO)	NO	NO REQUIRED INPUTS
Heat / Cold Producing Asset (YES/NO)	YES	INPUT HARMFUL TEMPERATURE
Maintenance Requires Lift System (YES/NO)	NO	NO REQUIRED INPUTS
INDEPENDENT INPUTS		
Located on Roof / Deck (YES/NO)	NO	NO OUTPUT
Outdoor Environment (YES/NO)	NO	NO OUTPUT
Located at a Ledge / Hole (YES/NO)	NO	NO OUTPUT
Exahust Producing Asset (YES./NO)	NO	NO OUTPUT
DEPENDENT INPUTS		
Disconnect Mechanism Location (Manual Only)		
Limit Switch Location (Where In Equipment)		
Harmful Force (Y/N)		
Disconnect Location (Panel Number)	P201	SENT TO DATA SHEET
Secondary Feed Location (Panel Number or None)	None	SENT TO DATA SHEET
Approximate Disconnect Distance (in feet)	84ft	SENT TO DATA SHEET
Valve Location (Valve Number)	V8	SENT TO DATA SHEET
Secondary Valve Location (Valve Number or None)	None	SENT TO DATA SHEET
Line Size (in inches)		
Approximate Valve Location Distance (in feet)	Local	SENT TO DATA SHEET
Harmful Temperature (Yes/No)	Yes	SENT TO DATA SHEET
Maintenance Working Height (in feet)		
Weight (in pounds)		
Support Structure Type (Platform, Threaded Rod, Etc.)		
Lead Present (Yes/No)	No	SENT TO DATA SHEET
Oxygen Deficient or Enriched / Carbon Monoxide Environment (Yes/No)	Yes	SENT TO DATA SHEET
Chemical No.1 Present	None	SENT TO DATA SHEET
Chemical No. 2 Present (Harmful Chemical or None)	None	SENT TO DATA SHEET
Chemical No. 3 Present (Harmful Chemical or None)	None	SENT TO DATA SHEET
Particulate Present (Yes/No)	Yes	SENT TO DATA SHEET
Asbestos Present (Yes/No)	No	SENT TO DATA SHEET
PCBs Present (Yes/No)	No	SENT TO DATA SHEET
Environmental Decibel Level (in dBA)	105 dBA	SENT TO DATA SHEET
Voltage (in volts)	480v	SENT TO DATA SHEET
Flooding Potential Exists (Yes/No)	No	SENT TO DATA SHEET
Milliservients of Radiation		
Chemical Storage (YES or None)	None	SENT TO DATA SHEET

Figure 46: ASIT Data Load for Boiler1 – FM Test Case No. 2

Table 28 presents the values required for the `Industrial Coal-fired Boiler` for this particular test case.

Table 28: Test Case No. 2 Relevant ASIT Data for `Boiler1`

Input Type	Inputs	Value
Primary	Environmental Air Quality	Yes
Dependent	Oxygen Deficient/Enriched/CO Env.	Yes
Dependent	Particulate Present	Yes
Primary	Environmental Decibel Level	Yes
Dependent	Environmental Decibel Level (in dBA)	105 dBA
Primary	Hazardous Energy/Live Current Present	Yes
Dependent	Disconnect Location	P201
Dependent	Approximate Disconnect Distance	84ft
Dependent	Voltage	480v
Primary	Manhole / Tank / Confined Space	Yes
Dependent	Valve Location	V8
Dependent	Approximate Valve Distance	Local
Dependent	Harmful Temperature	Yes
Primary	Heat/Cold Producing Asset	Yes
Dependent	Harmful Temperature	Yes

Figure 47 outlines the process the DRPS would execute in order to return results to the FM worker prior to executing the FM task.

Figure 47: Sequence Diagram for Boiler1 – FM Test Case No. 2

Upon receiving the work order and launching the DRPS, the system will identify the `Asset` and execute the `getPrimaryInputs`, `getDependentInputs`, and `getIndependentInputs` command. Executing these commands for the asset requiring maintenance returns the `PrimaryValues` (`EnvironmentalAirQuality`, `EnvironmentalDecibelLevel`, `HazardousEnergy`, `Manhole/Tank/ConfinedSpace`, and `Heat/ColdProducingAsset`), the `DependentValues` (`OxygenDeficient/Enriched/COEnvironment`,

ParticulatePresent, EnvironmentalDecibelLevel, DisconnectLocation, ApproxiamteDisconnectDistance, Voltage, ValveLocation, ApproximateDisconnectDistance, HarmfulTemperature). Once the DRPS returns all of the applicable values, the system can process the information and verify if a query should be launched. In this scenario, no query system launch is required and therefore the `getUserInput` action is bypassed. With all of the inputs identified, the system can evaluate and return the `MitigationProtocols` for the specific FM task. The protocols being returned in this test case address five hazards:

1. Environmental Air Quality
   a. `returnRespiratoyProtection`
   b. `returnAirMonitoring`
   c. `returnVentilation`
2. Environmental Decibel Level
   a. `returnHearingProtection/NoiseDampening`
   b. `returnNoiseMonitoring`
3. Hazardous Energy
   a. `returnLockout/Tagout`
   b. `returnHotSticks/Metering`
   c. `returnArcFlashProtection`
4. Confined Space
   a. `returnPermits`
5. Heat/Cold Producing Asset
   a. `returnBurnMitigation`

7.3. FM Test Case No. 3 – FACE Report 9717

A 37-year-old male maintenance electrician (the victim) died when his lower torso was crushed between the nip barrier (a wire-mesh gate) and the upper frame of a paper rewinder machine at a paper manufacturing facility. Without first de-energizing, locking out, and tagging the machine, the victim began to replace the arm for the limit switch that controlled upward movement of the nip barrier. He climbed an 8-foot stepladder to access the top of the machine where the switch was located, and leaned into the 16-inch opening between the top of the nip barrier and the upper frame of the machine. Co-workers observed him reaching with a screwdriver into the area where the switch was located. Apparently he inadvertently activated the limit switch and the nip barrier raised, carrying the victim and the stepladder upward and compressing both between the nip barrier and the upper frame of the machine. The victim's waist to lower

back area was crushed. A co-worker paged the plant safety watchman, who contacted the rescue squad. The rescue squad arrived within 2 minutes, and the victim was pronounced dead at the scene.

Based on the above FM test case, an ASIT can be loaded with the applicable safety information. ***Figure 48*** presents the data load applicable for this FM test case. Note: Not all of the necessary safety data presented in the ASIT is available in the FACE Report but has been added in order to present the appropriate data loading for this test case.

INITIAL INPUT VERIFICATION SYSTEM (IIVS)		
	ITEM NAME	**PaperRewinder**
Framework Rules Functionality	**Input Data**	**Backgroud**
PRIMARY INPUTS		
Manual Crushing / Rotating / Slicing Mechanism (YES / NO)	NO	NO REQUIRED INPUTS
Automated Crushing / Rotating / Slicing Mechanism (YES / NO)	YES	REQUIRE DISCONNECT LOCATION(S), LIMIT SWITCH LOCATION, APPROX. DISCONNECT DISTANCE & HARMFUL FORCE
Suction / Pressure Line (YES / NO)	NO	NO REQUIRED INPUTS
Overhead Equipment (YES / NO)	NO	NO REQUIRED INPUTS
Environmental Air Quality Hazards Present (YES/NO)	NO	NO REQUIRED INPUTS
Environmental Decibel Level Hazard (YES/NO)	NO	NO REQUIRED INPUTS
Hazardous Energy / Live Current Present (YES/NO)	YES	REQUIRE DISCONNECT LOCATION(S), LIMIT SWITCH LOCATION, APPROX. DISCONNECT DISTANCE, VOLTAGE
Manhole or Tank (YES/NO)	NO	NO REQUIRED INPUTS
Hazardous Chemical Production Transmission (YES/NO)	NO	NO REQUIRED INPUTS
Radiation (YES/NO)	NO	NO REQUIRED INPUTS
Heat / Cold Producing Asset (YES/NO)	NO	NO REQUIRED INPUTS
Maintenance Requires Lift System (YES/NO)	YES	REQUIRE WORKING HEIGHT
INDEPENDENT INPUTS		
Located on Roof / Deck (YES/NO)	NO	NO OUTPUT
Outdoor Environment (YES/NO)	NO	NO OUTPUT
Located at a Ledge / Hole (YES/NO)	NO	NO OUTPUT
Exahust Producing Asset (YES /NO)	NO	NO OUTPUT
DEPENDENT INPUTS		
Disconnect Mechanism Location (Manual Only)		
Limit Switch Location (Where In Equipment)	Top Right	SENT TO DATA SHEET
Harmful Force (Y/N)	Yes	SENT TO DATA SHEET
Disconnect Location (Panel Number)	P101	SENT TO DATA SHEET
Secondary Feed Location (Panel Number or None)	Local – Main Hydraulic	SENT TO DATA SHEET
Approximate Disconnect Distance (in feet)	45ft	SENT TO DATA SHEET
Valve Location (Valve Number)		
Secondary Valve Location (Valve Number or None)		
Line Size (in inches)		
Approximate Valve Location Distance (in feet)		
Harmful Temperature (Yes/No)		
Maintenance Working Height (in feet)	8ft	SENT TO DATA SHEET
Weight (in pounds)		
Support Structure Type (Platform, Threaded Rod, Etc.)		
Lead Present (Yes/No)		
Oxygen Deficient or Enriched / Carbon Monoxide Environment (Yes/No)		
Chemical No. 1 Present		
Chemical No. 2 Present (Harmful Chemical or None)		
Chemical No. 3 Present (Harmful Chemical or None)		
Particulate Present (Yes/No)		
Asbestos Present (Yes/No)		
PCBs Present (Yes/No)		
Environmental Decibel Level (in dBA)		
Voltage (in volts)	220v	SENT TO DATA SHEET
Flooding Potential Exists (Yes/No)		
Milliservients of Radiation		
Chemical Storage (YES or None)		

Figure 48: ASIT Data Load for PaperRewinder – FM Test Case No. 3

Table 29 presents the values required for the `PaperRewinder` for this particular test case.

Table 29: Test Case No. 3 Relevant ASIT Data for `PaperRewinder`

Input Type	Inputs	Value
Primary	Automated Crushing/Rotating/Slicing Mechanism	Yes
Dependent	Limit Switch Location	Top Right
Dependent	Harmful Force	Yes
Dependent	Disconnect Location	P101
Dependent	Secondary Feed	Local – Main Hydraulic
Dependent	Approximate Disconnect Distance	45ft
Primary	Hazardous Energy	Yes
Dependent	Voltage	220v
Dependent	Disconnect Location	P101
Dependent	Secondary Feed	Local – Main Hydraulic
Dependent	Approximate Disconnect Distance	45ft
Primary	Maintenance Requires Lift System	Yes
Dependent	Working Height	8ft

Figure 49 outlines the process the DRPS would execute in order to return results to the FM worker prior to executing the FM task.
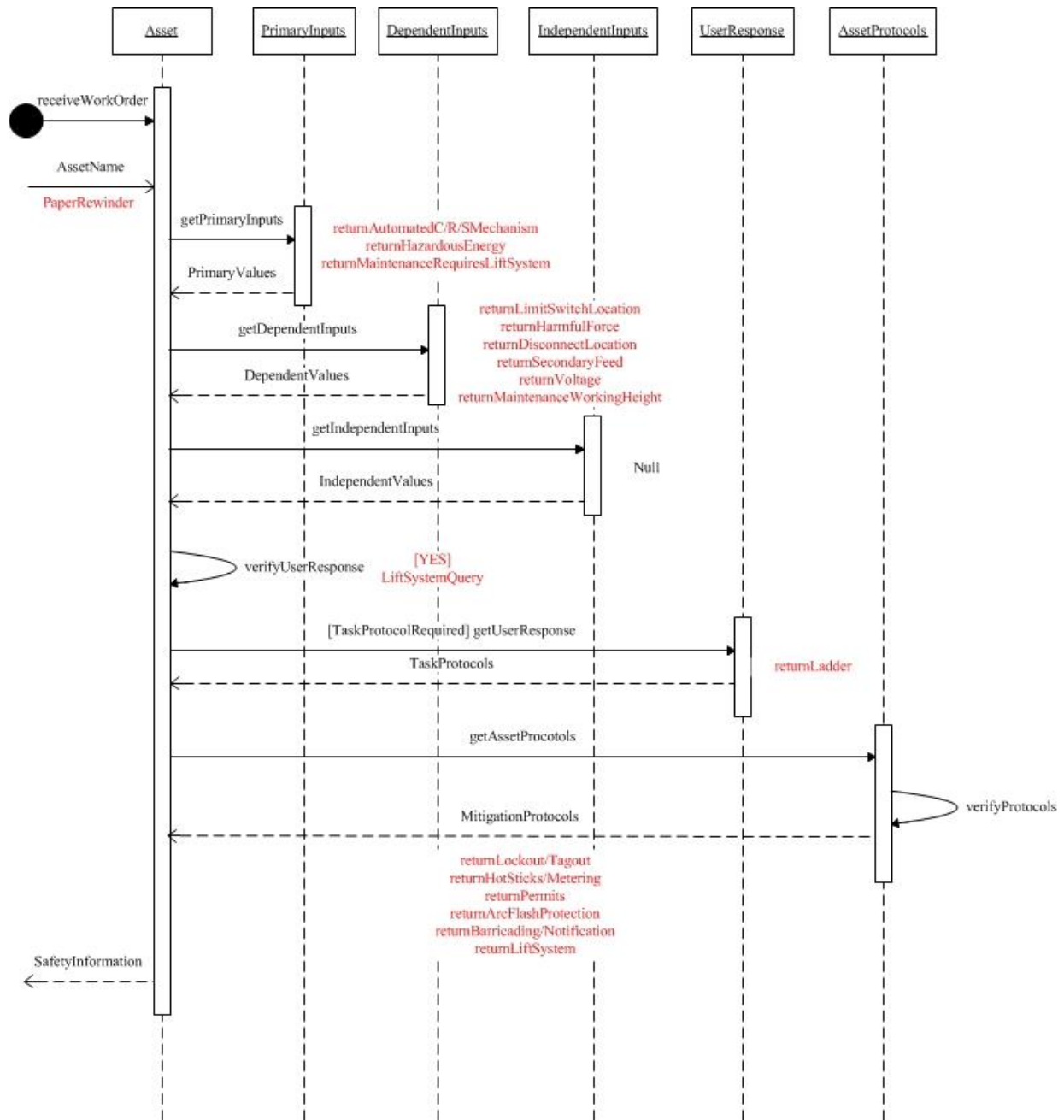
Figure 49: Sequence Diagram for PaperRewinder – FM Test Case No. 3

Upon receiving the work order and launching the DRPS, the system will identify the Asset and execute the getPrimaryInputs, getDependentInputs, and getIndependentInputs command. Executing these commands for the asset requiring maintenance returns the PrimaryValues (AutomatedCrushing/Rotating/SlicingMechanism, HazardousEnergy, & MaintenanceRequiresLiftSystem), the DependentValues (LimitSwitchLocation, HamrfulForce, DisconnectLocation, & SecondaryFeed, Voltage,

`MaintenanceWorkingHeight`). In this test case, there are no `IndependentValues` and therefore the system will not return a value. Once the DRPS returns all of the applicable values, the system can process the information and verify if a query should be launched. In this scenario, the `MaintenanceRequiresLiftSystem` input has been assigned a value and therefore the system will query the user on which lift system will be utilized. From the FM test case an election of `Ladder` is made. With all of the inputs identified, the system can evaluate and return the `MitigationProtocols` for the specific FM task. The protocols being returned in this test case address three hazards:

1. Hazardous Energy
   a. `returnLockout/Tagout`
   b. `returnHotSticks/Metering`
   c. `returnPermits`
   d. `returnArcFlashProtection`
2. Automated Crushing/Slicing/Rotating Mechanism
   a. `returnBarricading/Notification`
3. Falls
   a. `returnLiftSystem` (Ladder Protocol)

The above test case represents the parent asset group (`PaperRewinder`) and all safety inputs requiring values are present.

7.4. FM Test Case No. 4 – Liquid Anhydrous Ammonia & Oil Separation

The following test case was validated by an Operations Manager and Arena Technician at a large civic center (with ice rink) in the Southeastern USA.

A FM Worker at an ice skating rink needs to maintain the ammonia tanks that cool a brine solution required for the sheet of ice. The rink utilizes an indirect brine system in order to facilitate heat exchange. The brine solution runs through the ice floor, absorbing the floor's heat and keeping the ice sheet cool. When the brine solution returns to the compressor system, it is run through coils housed in a tank filled with ammonia in order to draw the heat out of the brine solution, cooling the solution to be sent back to the ice rink floor. The ammonia compressor in the system utilizes self-lubrication in order to get oil to the mobile parts of the compressor. Over time, the oil seeps from the compressor crankcase and becomes mixed with the liquid anhydrous ammonia. In order to maintain the thermodynamic efficiency of the ammonia surrounding the brine coils, the oil and ammonia mix needs to be drained from an access valve on the ammonia tanks and

the oil needs to be separated from the ammonia. Draining this mixture puts the FM worker in direct contact with the dangerous anhydrous ammonia. In addition, the tanks are located in a noisy compressor room.

Based on the above FM test case, an ASIT can be loaded with the applicable safety information. **Figure 50** presents the data load applicable for this FM test case.

INITIAL INPUT VERIFICATION SYSTEM (IIVS)		
	ITEM NAME	**AmmoniaTank1**
Framework Rules Functionality	**Input Data**	**Backgroud**
PRIMARY INPUTS		
Manual Crushing / Rotating / Slicing Mechanism (YES / NO)	NO	NO REQUIRED INPUTS
Automated Crushing / Rotating / Slicing Mechanism (YES / NO)	NO	NO REQUIRED INPUTS
Suction / Pressure Line (YES / NO)	YES	REQUIRE VALVE LOCATION, LINE SIZE, APPROX. VALVE DISTANCE, HARMFUL FORCE
Overhead Equipment (YES / NO)	NO	NO REQUIRED INPUTS
Environmental Air Quality Hazards Present (YES/NO)	YES	AIR QUALITY HAZARD TYPE DESIGNATION
Environmental Decibel Level Hazard (YES/NO)	YES	HEARING PROTECTION REQUIRED
Hazardous Energy / Live Current Present (YES/NO)	NO	NO REQUIRED INPUTS
Manhole or Tank (YES/NO)	YES	REQUIRE FLOOD/SUBMERGE POTENTIAL, CHEMICAL, VALVE, APPROX VALVE DISTANCE
Hazardous Chemical Production Transmission (YES/NO)	YES	REQUIRE CHEMICALS PRESENT
Radiation (YES/NO)	NO	NO REQUIRED INPUTS
Heat / Cold Producing Asset (YES/NO)	YES	INPUT HARMFUL TEMPERATURE
Maintenance Requires Lift System (YES/NO)	NO	NO REQUIRED INPUTS
INDEPENDENT INPUTS		
Located on Roof / Deck (YES/NO)	NO	NO OUTPUT
Outdoor Environment (YES/NO)	NO	NO OUTPUT
Located at a Ledge / Hole (YES/NO)	NO	NO OUTPUT
Exahust Producing Asset (YES./NO)	NO	NO OUTPUT
DEPENDENT INPUTS		
Disconnect Mechanism Location (Manual Only)		
Limit Switch Location (Where In Equipment)		
Harmful Force (Y/N)	No	SENT TO DATA SHEET
Disconnect Location (Panel Number)		
Secondary Feed Location (Panel Number or None)		
Approximate Disconnect Distance (in feet)		
Valve Location (Valve Number)	V112	SENT TO DATA SHEET
Secondary Valve Location (Valve Number or None)	None	SENT TO DATA SHEET
Line Size (in inches)	6in	SENT TO DATA SHEET
Approximate Valve Location Distance (in feet)	Local	SENT TO DATA SHEET
Harmful Temperature (Yes/No)	No	SENT TO DATA SHEET
Maintenance Working Height (in feet)		
Weight (in pounds)		
Support Structure Type (Platform, Threaded Rod, Etc.)		
Lead Present (Yes/No)	No	SENT TO DATA SHEET
Oxygen Deficient or Enriched / Carbon Monoxide Environment (Yes/No)	No	SENT TO DATA SHEET
Chemical No.1 Present	Ammonia	SENT TO DATA SHEET
Chemical No. 2 Present (Harmful Chemical or None)	None	SENT TO DATA SHEET
Chemical No. 3 Present (Harmful Chemical or None)	None	SENT TO DATA SHEET
Particulate Present (Yes/No)	No	SENT TO DATA SHEET
Asbestos Present (Yes/No)	No	SENT TO DATA SHEET
PCBs Present (Yes/No)	No	SENT TO DATA SHEET
Environmental Decibel Level (in dBA)	112	SENT TO DATA SHEET
Voltage (in volts)		
Flooding Potential Exists (Yes/No)	No	SENT TO DATA SHEET
Milliservients of Radiation		
Chemical Storage (YES or None)	Yes	REQUIRE CHEMICALS PRESENT

Figure 50: ASIT Data Load for AmmoniaTank1 – FM Test Case No. 4

Table 30 presents the values required for the `AmmoniaTank` for this particular test case.

Table 30: Test Case No. 4 Relevant ASIT Data for `AmmoniaTank1`

Input Type	Inputs	Value
Primary	Suction/Pressure Lines	Yes
Dependent	Valve Location	V112
Dependent	Line Size	6in
Dependent	Approximate Valve Location Distance	Local
Primary	Environmental Air Quality	Yes
Dependent	Chemical No. 1 Present	Liquid Anhydrous Ammonia
Primary	Environmental Decibel Level Hazard	Yes
Dependent	Environmental Decibel Level	112dBA
Primary	Manhole / Tank / Confined Space	Yes
Dependent	Valve Location	V112
Dependent	Approximate Valve Location Distance	Local
Dependent	Chemical Storage	Yes
Primary	Hazardous Chemical Production/Transmission	Yes
Dependent	Chemical No. 1 Present	Liquid Anhydrous Ammonia
Primary	Heat / Cold Producing Asset	Yes
Dependent	Harmful Temperature	No

Figure 51 outlines the process the DRPS would execute in order to return results to the FM worker prior to executing the FM task.
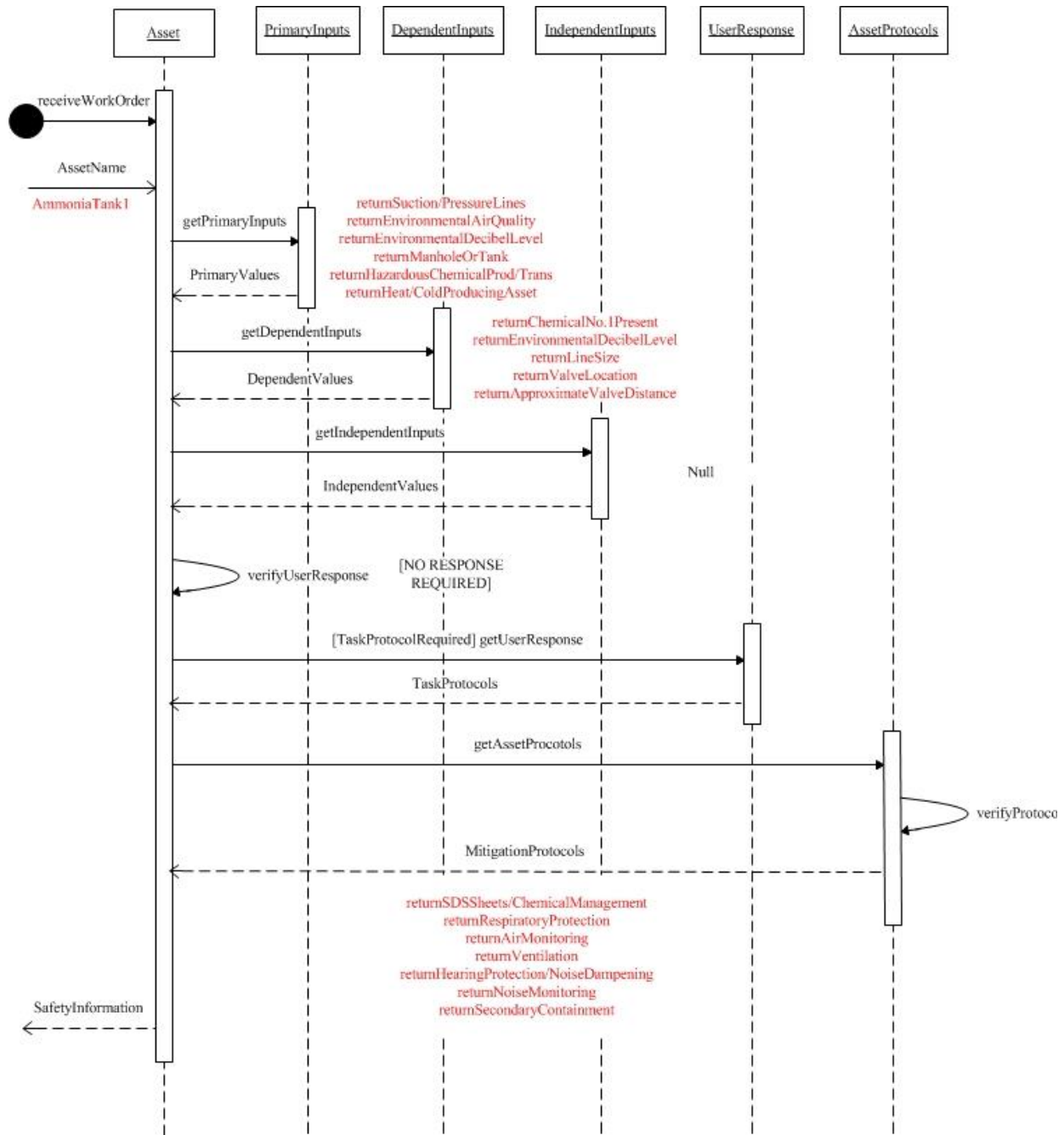
Figure 51: Sequence Diagram for AmmoniaTank1 – FM Test Case No. 4

Upon receiving the work order and launching the DRPS, the system will identify the Asset and execute the getPrimaryInputs, getDependentInputs, and getIndependentInputs command. Executing these commands for the asset requiring maintenance returns the PrimaryValues (Suction/PressureLines, EnvironmentalAirQuality, EnvironmentalDecibelLevel, Manhole/Tank/ConfinedSpace,

```
ChemicalProduction/Transmission,        Heat/ColdProducingAsset),        the
DependentValues    (ChemicalNo.1Present,    EnvironmentalDecibelLevel,
LineSize,ValveLocation, ApproximateValveDistance).
```
Once the DRPS returns all of the applicable values, the system can process the information and verify if a query should be launched. In this scenario, no query system launch is required and therefore the `getUserInput` action is bypassed. With all of the inputs identified, the system can evaluate and return the `MitigationProtocols` for the specific FM task. The protocols being returned in this test case address three hazards:

1. Environmental Air Quality
   a. `returnRespiratoyProtection`
   b. `returnAirMonitoring`
   c. `returnVentilation`
2. Environmental Decibel Level
   a. `returnHearingProtection/NoiseDampening`
   b. `returnNoiseMonitoring`
3. Chemical Production / Transmission
   a. `returnSDSSheets/ChemicalManagement`
   b. `returnSecondaryContainment`

7.5. DRPS Proof of Concept

In order to achieve the final validation step set forth by Turkaslan-Bulbul and Akin (2007), the functional usage of the data model or Support, the research graphically presents a conceptual GUI in correlation with the sequence diagram presented in FM Test Case No. 4 – Liquid Anhydrous Ammonia & Oil Separation. Developing and validating the DRPS conceptual GUI executes the final objectives of this research, as well as completes the final phases of the Six Sigma methodology - Design and Verify. Utilizing the conceptual GUI with the sequence diagrams presents a visual representation of the user interface and the background information being retrieved/returned by the DRPS. These combined graphics serve as a proof of concept for the DRPS.

The basis of the DRPS developed within this research is BIM-based, launched within an appended Autodesk Navisworks model as presented in Chapter 5. In execution, this requires the utilization of the Autodesk Navisworks Software Developer's Kit (SDK) over the Navisworks .NET Application Programming Interface (API). Conceptually, the DRPS is a "Plug-in" to Navisworks. Autodesk Inc. (2016) states, "(A) plug-in allows (the user) to write additional functions that extend the Autodesk Navisworks

product." For this research, the BIM-based safety framework would utilize Navisworks' data storage capacity and graphics and extend the software by adding the DRPS on top of the existing system. The following section provides the conceptual graphics, built in Java Eclipse Window Builder, in correlation with the sequence diagrams to present a proof of concept to the functional usage of the DRPS. The model utilized within the following section is representative and does not include all of the graphics within a complete compressor package.

7.5.1. DRPS Proof of Concept Test Case

The following is a restating of Test Case No. 4 – Liquid Anhydrous Ammonia & Oil Separation:

A FM Worker at an ice skating rink needs to maintain the ammonia tanks that cool a brine solution required for the sheet of ice. The rink utilizes an indirect brine system in order to facilitate heat exchange. The brine solution runs through the ice floor, absorbing the floor's heat and keeping the ice sheet cool. When the brine solution returns to the compressor system, it is run through coils housed in a tank filled with ammonia in order to draw the heat out of the brine solution, cooling the solution to be sent back to the ice rink floor. The ammonia compressor in the system utilizes self-lubrication in order to get oil to the mobile parts of the compressor. Over time, the oil seeps from the compressor crankcase and becomes mixed with the liquid anhydrous ammonia. In order to maintain the thermodynamic efficiency of the ammonia surrounding the brine coils, the oil and ammonia mix needs to be drained from an access valve on the ammonia tanks and the oil needs to be separated from the ammonia. Draining this mixture puts the FM worker in direct contact with the dangerous anhydrous ammonia. In addition, the tanks are located in a noisy compressor room.

The behavior of the DRPS is dictated by the sequence diagram presented in *Figure 51*. In this section, each process that the GUI initiates will have a correlating figure presenting the associated step in the sequence diagram.

STEP 1 - Upon receipt of the work order, the FM user will launch the DRPS plug-in within the appended Navisworks model (*Figure 52*).

STEP 2 **-** Launching the DRPS will initiate the system to request the `AssetName` as shown in *Figure 53*.

STEP 3 - Upon selection by the user, the Safety Inputs and Values are presented in the asset properties under the "DRPS" tab. Once the user is satisfied with the asset selection, the "Run" button launches the

DRPS retrieval process. During this process, the DRPS is actively retrieving the `PrimaryInputs,` `DependentInputs,` and `IndependentInputs` and their associated values (***Figure 54***).

STEP 4 - Once the system has retrieved all of the inputs and values, the DRPS will call on itself to evaluate the returns in order to `verifyUserResponse`. If the system identifies a safety input that requires additional user input, the system would `getUserResponse`. In this test case, there is no `TaskProtocolRequired` and therefore this step is bypassed, moving directly to `AssetProtocols` retrieval as shown in ***Figure 55***.

STEP 5 - Upon retrieval of the `AssetProtocols`, the system will call on itself a final time in order to eliminate protocol redundancies as many of the Safety Inputs have shared `MitigationProtocols`. The returned `MitigationProtocols` are presented to the user as `SafetyInformation` (***Figure 56***), which is in a format ready for user consumption.
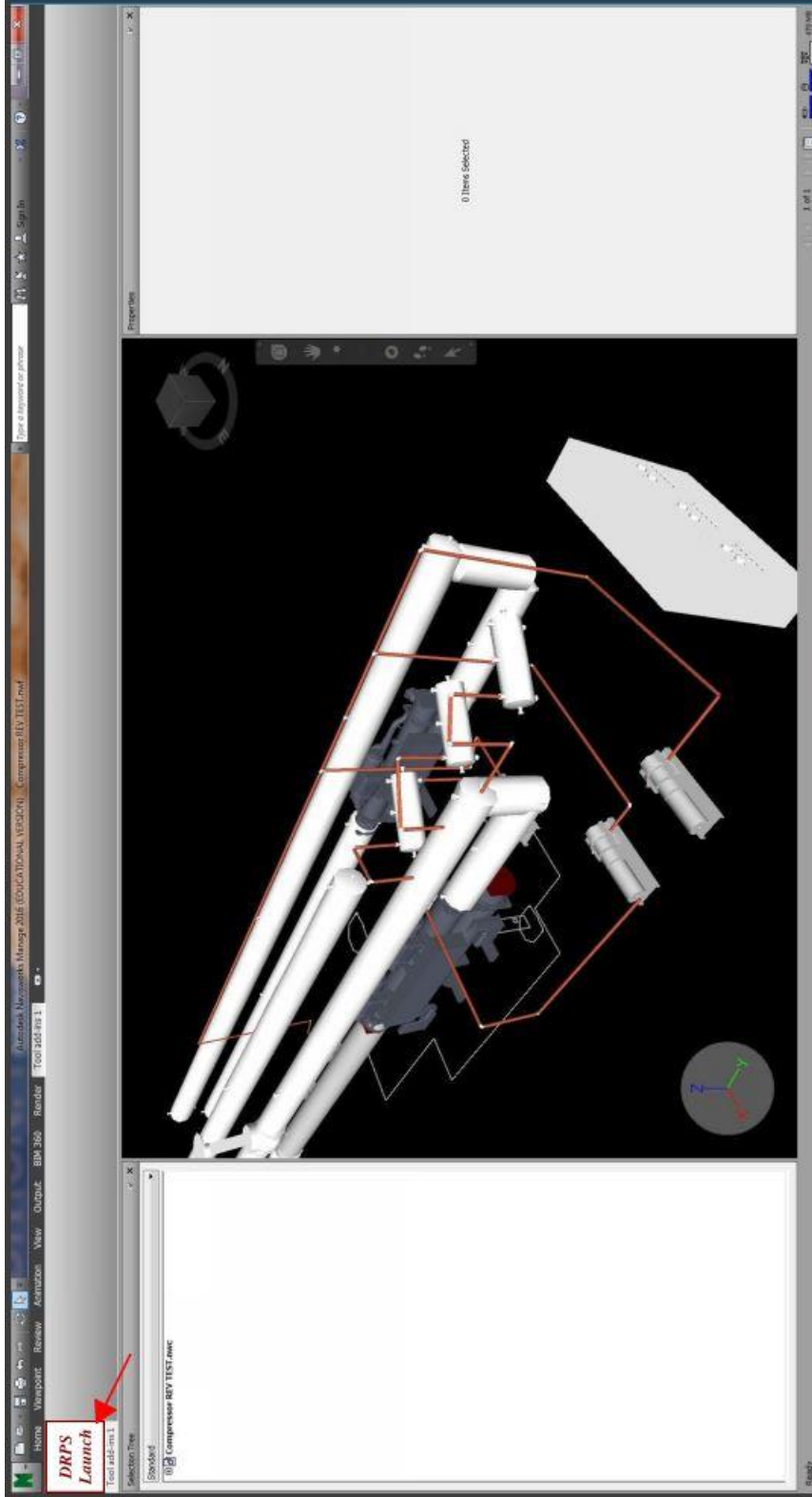
*Figure 52: Step 1 - Launch of the DRPS Plug-in*
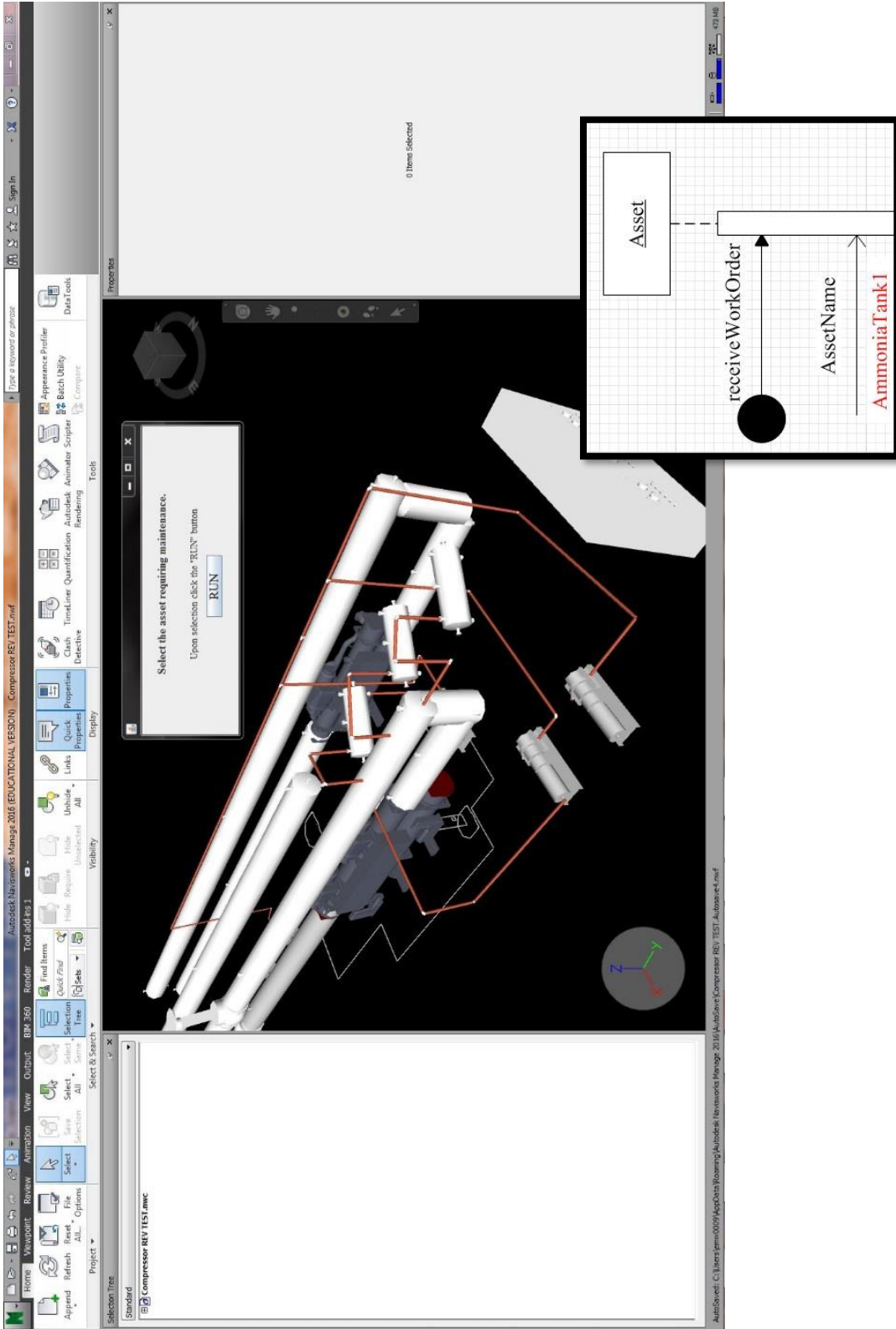
*Figure 53: Step 2 - The DRPS Requesting the AssetName from the User*
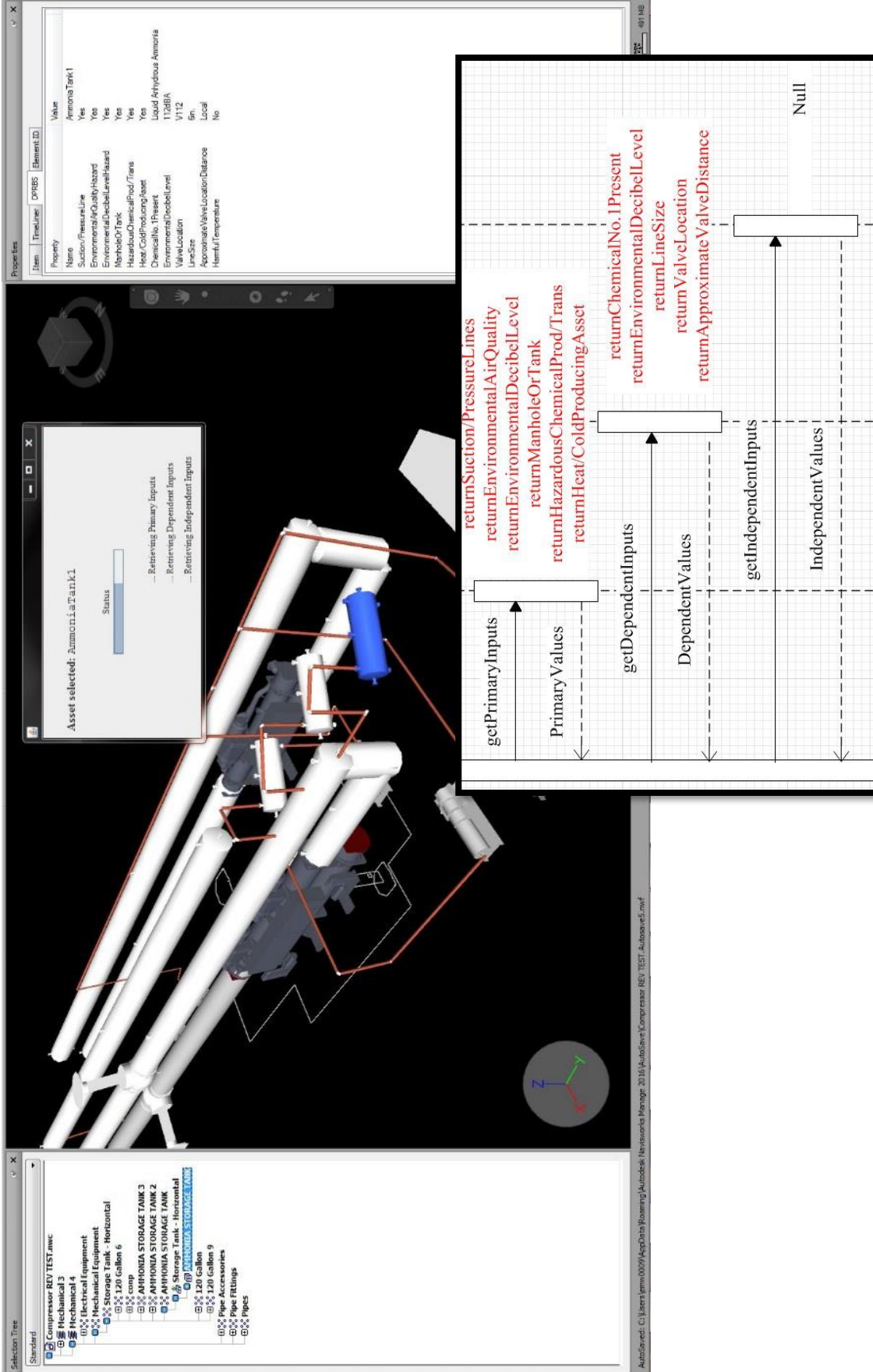
Figure 54: Step 3 - The DRPS Retrieving Safety Inputs and Values
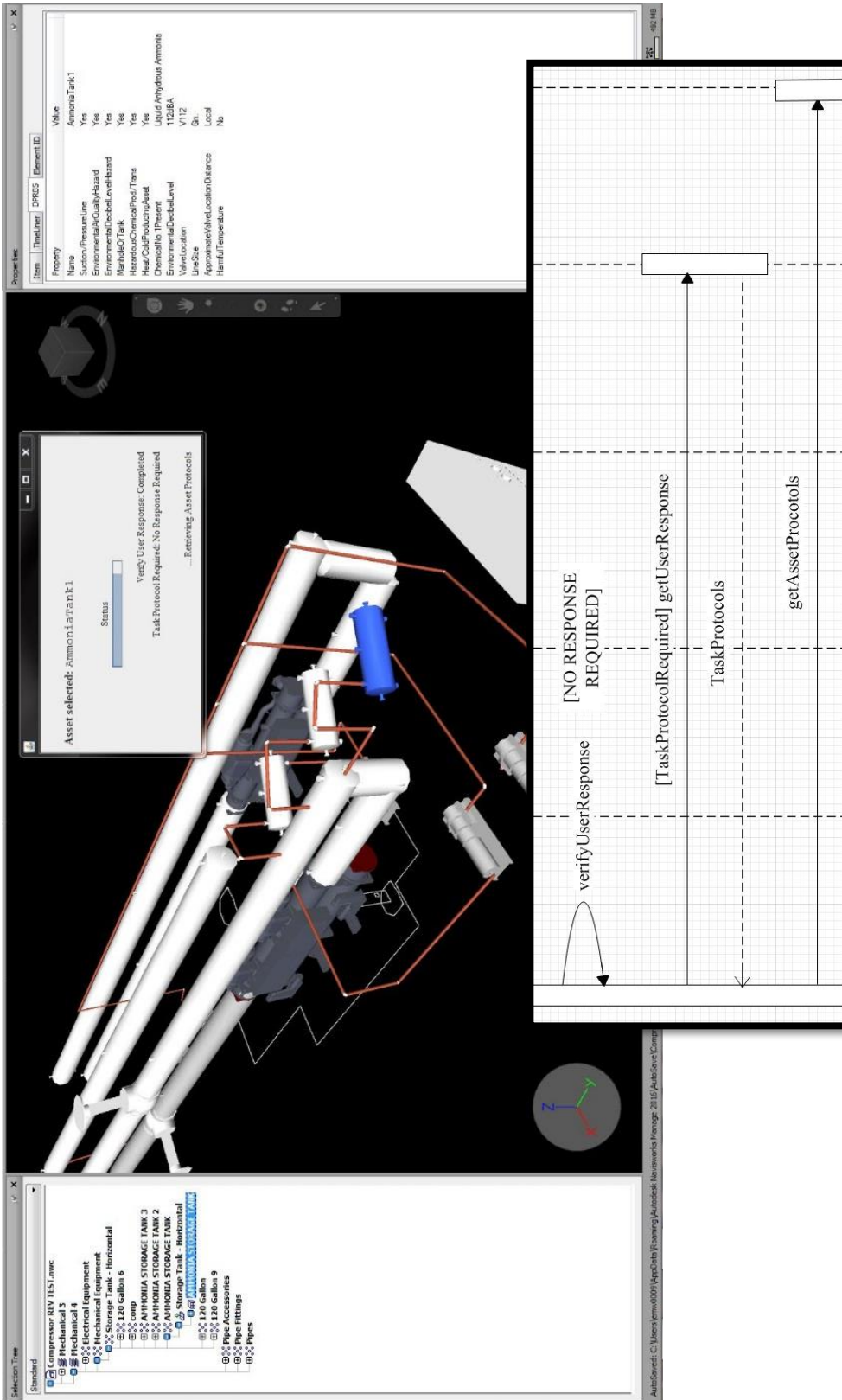
Figure 55: Step 4 - The DRPS Evaluating the Returned Safety Inputs and Retrieving the AssetProtocols

133
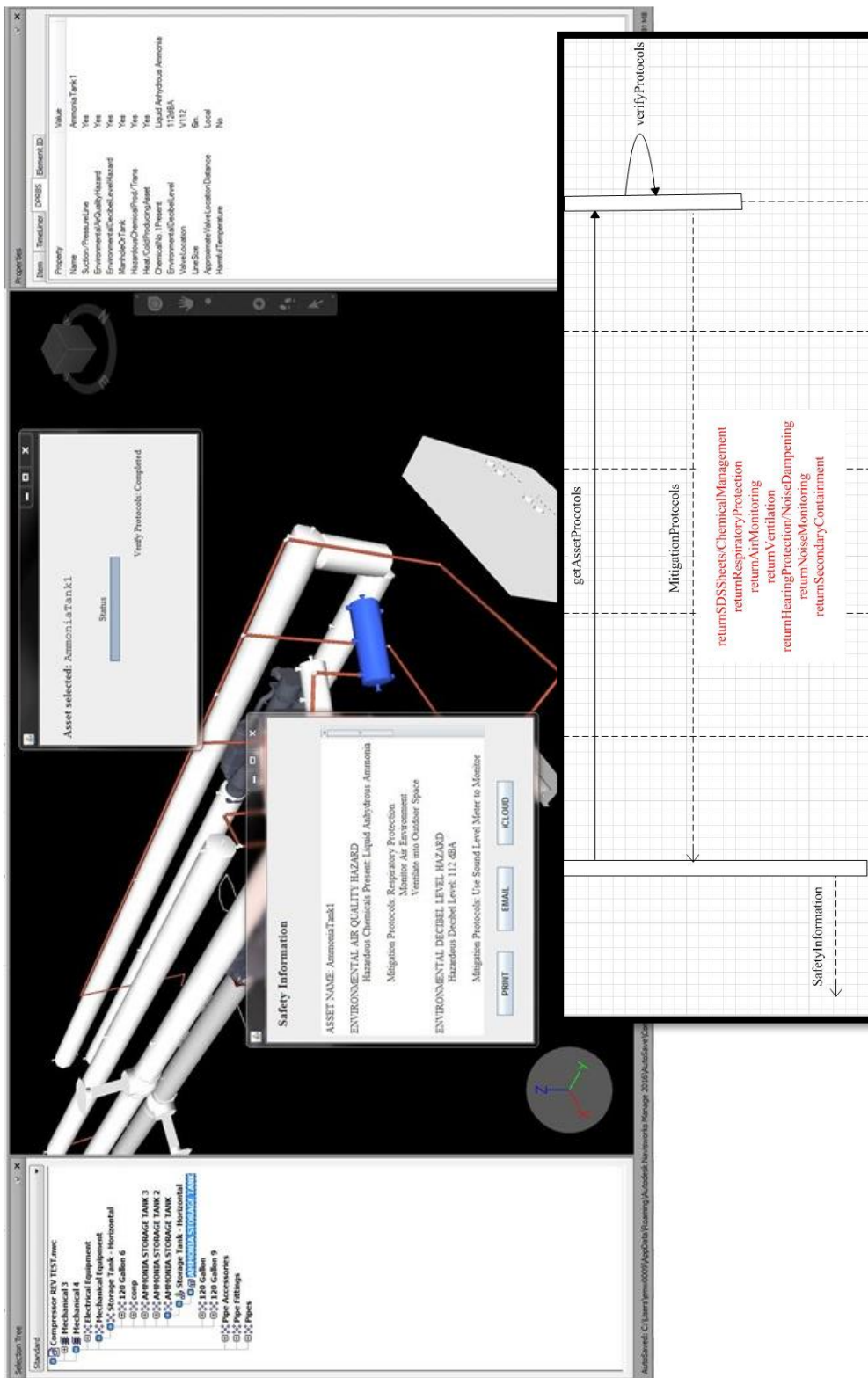
Figure 56: Step 5 - SafetyInformation being Presented Upon Verification of the Retrieved AssetProtocols

7.6. Conceptual Walk-through

The final validation phase of the research includes a conceptual walk-through of the entire proposed framework with industry professionals. The conceptual walk-through is intended to present the framework in order to obtain feedback that could guide the future research and continue to evolve the framework. Utilizing a presentation style format, followed by a conversational exchange, critiques, evaluations, and positives regarding the framework are discussed. For this research, the conceptual walk-through included two safety experts. *Table 31* presents the experts included in the walk-through.

Table 31: Conceptual Walk-through Participants

Date Interviewed	Pseudonym	Position	Company Type
9/26/16	Ryan	Facilities Safety Inspector	Large University: East Region USA
9/26/16	Edward	Facilities Safety Coordinator	Large University: East Region USA

The results of this meeting were largely positive towards the concepts and functionality.

- *"From a beginning structural aspect, it's pretty good. The concepts are there."*
- *"I think the functions are good, the yes/no input... it is as simple as it gets."*
- *"The system is easy enough, there is no rocket science there."*

Future research and recommendations for the framework fell within three categories.

Presentation of `SafetyInformation`

Identify the best mechanism to deliver the safety information to the user. Currently the system presents text-based safety information, but are different medias more appropriate (e.g. images, videos, etc.)

- *"Safety Data Sheets, is that something that you could put in there?"*

BIM Model / Technology learning curve

Maximizing the usability of the system to reduce the learning curve for staff

- *"What about those older individuals who are not very computer literate. How do you propose the system to them..."*

<u>Managerial work flow and model updates</u>

Each company using the system will need to identify their particular work flow for safety data loading, backchecking, and model updates

- *"It's great stuff and the Return on Investment is there, but getting there is the challenge."*
- *"Who is maintaining that (the model), you would almost see a person just maintaining the models and information... We are moving to a GIS system, which reads well with BIM, so the need is there."*
- [In reference to placing values into the ASIT]*"Someone could input the wrong values"*

By expanding on the positives from the conceptual walk-through and addressing the items within the future research and recommendations, the framework will continue to evolve. Chapter 8 will address a few of the future research recommendations and summarize the work executed within this research.

8. CONCLUSION AND FUTURE RESEARCH

The inconvenience of having to retrieve uncategorized safety related information from a number of fragmented sources, retards the FM task, requiring time sensitive activities to be rushed, which has been shown to be directly correlated to injuries, illnesses, and fatalities. In an attempt to mitigate facilities management incidents, a BIM-based framework has been developed to deliver comprehensive safety information to FM staff efficiently. Execution of the framework required completion of four objectives:

- Objective No. 1 – Define, categorize, and standardize asset specific safety information applicable to falls, contact with / struck by, and harmful environments & substances.
- Objective No. 2 – Present a data path through defined transfer mechanisms in order to get safety information, in various formats, from design/construction to FM personnel into a singular repository.
- Objective No. 3 – Develop a data retrieval and processing system (DRPS) and conceptual graphical user interface (GUI), presented through graphics, to represent the interface between FM worker and DRPS.
- Objective No. 4 – Validation

This chapter summarizes how the research achieved these objectives, how this research contributes to the body of knowledge, and avenues for continuation of the research.

8.1. Execution of Research Objectives

8.1.1. Objective No. 1 – Define, Categorize, and Standardize Asset Safety Information

In order to develop a BIM-based system to process asset specific safety information and present the information to FM staff prior to the execution of an FM task, identifying what information is relevant is the initial step. Through a number of qualitative data collection methods, a comprehensive list of safety inputs (hazards) and protocols (mitigation techniques) regarding falls, contact with / struck by, and harmful environments & substances were developed. Structuring the static safety information into categories and utilizing the inherent relationships within the data (primary, dependent, and independent), allows for the development of an approach to standardize the safety information based on specific asset groups.

The Asset Safety Identification Tool (ASIT) guides the user through the development of asset specific safety properties. By utilizing known asset information, the formulated spreadsheet can produce a standardized list of safety properties based on the responses to queries within the ASIT. Running facility specific assets through the ASIT provides FM staff with a list of safety properties that require values based

on the specifics of individual assets. The safety properties can be loaded into a singular BIM-based repository through existing data transfer mechanisms.

8.1.2. Objective No. 2 – Data Transfer

Development of a data processing and retrieval system to return asset specific safety information, requires the data be located in a singular data repository. Historically, safety information applicable to the safe maintenance of a facility is fragmented, uncategorized, and turned over to FM staff in a number of different formats (models, docs, pdfs, etc.). The research addresses the fragmentation and categorization of the safety information through the ASIT, but mitigation of the various formats requires the research to identify a data path that centralizes the safety properties in a singular repository. Autodesk Navisworks is used within this research as this BIM-based repository. Navisworks was selected for this research for three reasons:

1. Interoperability – Safety properties loaded into native models can be exported with Autodesk or IFC file extensions, allowing for information to be transferred among software without data loss.
2. Existing Data Transfer Mechanisms – Entities that do not have compatible native models or do not have modeling capabilities will need a secondary mechanism in order to transfer applicable safety properties into the BIM-based Navisworks repository. Using tools built into the Navisworks system, Selection Inspector and DataTools, safety properties can be exported, adjusted in a CSV file, and re-imported back into the BIM model.
3. Navisworks API System – Navisworks allows for "plug-ins" to be written over the Navisworks' .NET Application Programming Interface to extend the base software. Building the Data Processing and Retrieval System (DRPS) with the API negates the need to develop a standalone software with the same interoperability, data transfer/storage capabilities, and graphics that is already built into Navisworks.

Once the safety properties are located within a singular BIM-based repository, the developed Data Processing and Retrieval System (DRPS) can interact with the stored data in order to present asset specific safety information to the FM user.

8.1.3. Objective No. 3 – DRPS and Conceptual GUI

Through UML Class and Sequence Diagrams, the structure of the DRPS is presented. The research presents how the DRPS will retrieve and process the safety properties and values stored within the Navisworks repository model using real-life FM test cases. Combining these structural and behavioral diagrams with a conceptual graphical user interface allows for the system functionality to be further presented with graphical context of the user interface.

8.1.4. Objective No. 4 - Validation

Throughout the research, validation of the data and developed processes was of paramount importance. Using data validation interviews, the safety inputs and mitigation techniques obtained during the data collection phase were reviewed, adjusted, and finalized with industry FM safety experts. Using the validated data, the ASIT and the DRPS are developed. As each system was executed, four test cases were used in order to validate that the systems were robust enough to handle diverse FM tasks. As each individual system evolved and the relational connection between the systems was defined (*Figure 57*), a proof of concept was completed to present the comprehensive functionality of the ASIT, DRPS, and conceptual GUI.
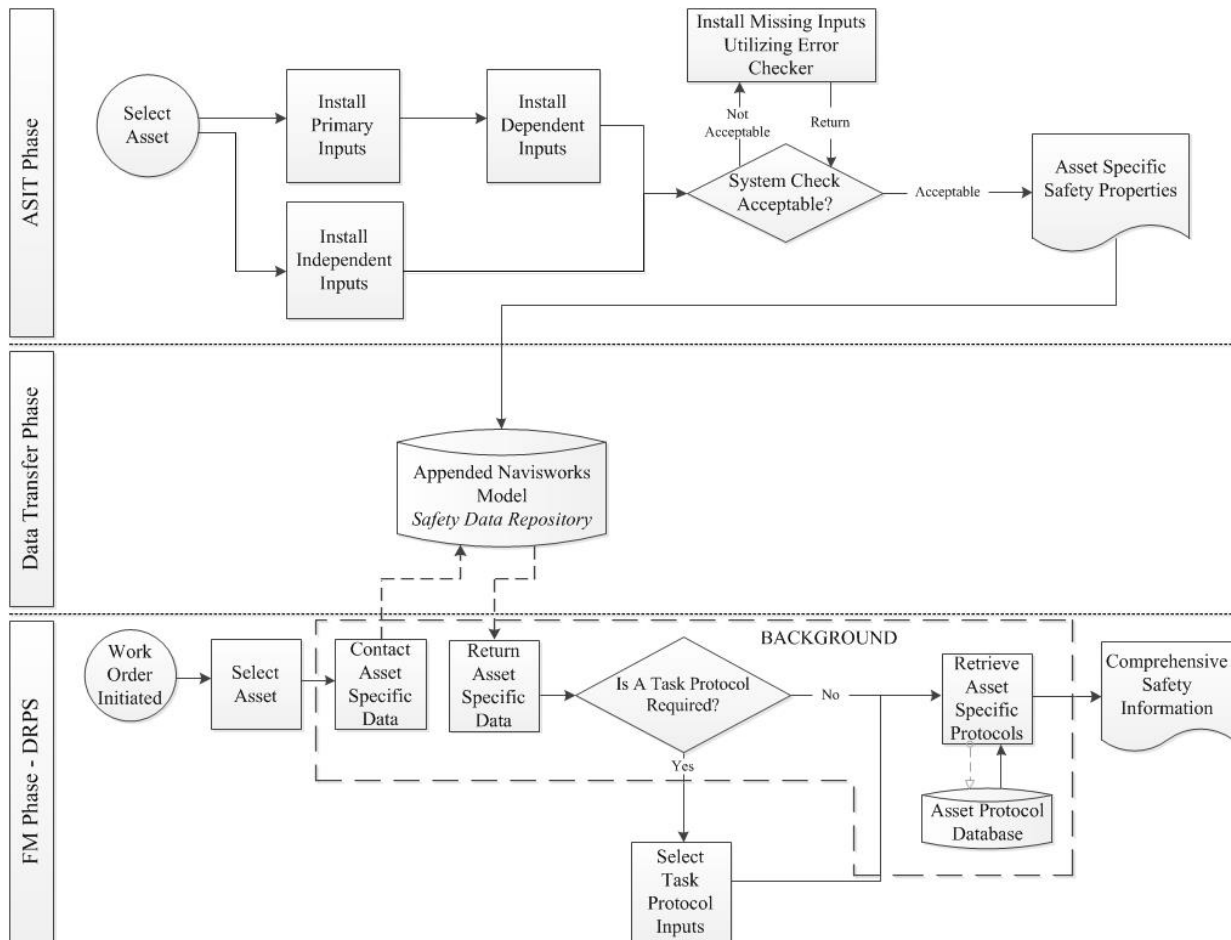

Figure 57: BIM-Based Safety Framework Processes by Phase

8.2. Contributions

The two major contributions of this research is the categorization of safety information and the development of the Asset Safety Identification Tool (ASIT).

The development of categorized safety information regarding falls, contact with / struck by, and harmful environments & substances is a contribution to the field. Although the FM hazards and associated mitigation techniques were available, the information was fragmented, uncategorized, and left at the discretion of the FM worker of its relevance to asset safety. The benefit of having this safety information available in a comprehensive list focuses the attention of an FM worker to the inherent dangerous of asset safety without the need to reference multiple documents.

The Asset Safety Identification Tool (ASIT) is a formulated spreadsheet, that when executed can produce safety properties for an asset group. The ASIT guides the user through safety property development by requiring responses to queries based on known information about the asset and the research identified safety inputs. This tool will allow for safety property development for any asset group run through the system. The benefit of being able to identify safety properties for an asset group mitigates the fragmentation of safety information and standardizes how the information is structured before being transferred to FM staff.

8.3. Future Research

The framework presented in this research is intended to get research defined safety inputs and protocols to FM workers prior to a FM task through the use of a DRPS. The research covers what safety information is applicable to FM workers, how the data is loaded, how the data is transferred to a repository, and how the DRPS interacts with the stored safety information. Creating solutions for these objectives meets the intent of this research; however, a number of research paths can be explored to continuously evolve the framework. The following section presents four new objectives that future research could address.

8.3.1. Expansion of the DRPS

The Data Retrieval and Processing System conceptually pulls stores information from the Navisworks repository, processes the data, verifies the need for additional user data, re-processes, and presents the information. In this current format, the system relies heavily on user input and understanding of returned results. Based on the conceptual walk-throughs with the industry experts, minimizing the amount of information processing the user must do and maximizing the functionality of the system would help mitigate the learning curve and organizational implementation. Expanding the DRPS to a rule based system would

add processing power of the current system and further alleviate the human element to FM hazard mitigation. Examples of expanded functionality could include:

- A rule-based and/or artificial intelligence system that extends the current process by considering known asset information, learning patterns, and eliminating possibilities based on the specific asset
- Integration of the ASIT to the DRPS for a simplified data loading mechanism
- Expand the system to process more than one asset in a single run

8.3.2. Presentation of `SafetyInformation`

As shown in *Figure 56*, `SafetyInformation` is currently presented in text format. Based on the DRPS functionality, upon receipt of the applicable protocols the system will structure the returns in order to present the hazards and mitigation techniques to the user. This `SafetyInformation` step presents the `MitigationProtocols` to the user in a format that maximizes information consumption. In order to improve the efficiency and effectiveness of the system, a strong evaluation of how the `SafetyInformation` is presented to the user is important. A literature review regarding effective mechanisms of information dissemination will need to be executed and a decision addressing the platform of `SafetyInformation` deliverance (text, audio, video, etc.) should be made. In addition to selection of a media type, addressing the format and structure of how the media is presented is also a potential avenue of future research.

8.3.3. Prototyping and Usability

Within the scope of this research, the DRPS and GUI are represented schematically through UML diagrams and conceptual visual aids. In order to test the functionality of the system in full application, a prototype of the initial design will need to be coded and launched over the Navisworks API. Alpha tests would be initiated to verify that the system architecture is commensurate with expectations and revisions to the structural and behavioral design of the system can be made as needed. With a functioning prototype, additional studies could be executed to test the usability and interface of the system. The prototyping phase could also be utilized to launch the system using various hardware (e.g. mobile tablets, smartphones, etc.). Utilizing mobile platforms would expand the usability of the system, as well as prevent the user from having to run the DRPS from a central hub.

8.3.4. Organizational Implementation

As with the implementation of any new technology, a workflow of how the systems will be initiated, executed, and updated needs to be developed within an organization. The processes designed within this research, specifically the ASIT and DRPS, will require a market study of how organizations plan to

approach the usage of the system. For example, adding values to the ASIT is a crucial step in the functionality of the system. Improper loading of data could lead to missing or incorrect safety inputs or mitigation techniques. This would undermine the entire system functionality. A close evaluation of organizational setup, available infrastructure, and best practices could lead to a structured workflow that may include additional contract entities (e.g. utilizing the manufacturer for ASIT data loading). Additionally, the legal aspect of where liability lies in utilizing a system that produces safety information would need to be addressed. Findings of this study could lead to adjustments to the usability, hardware, and functionality of the developed systems.

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Appendix A: Definition of Terms

Definition of terms as it pertains to this research.

Building Information Modeling (BIM): A computer-generated model containing precise geometry and relevant data for support during construction, fabrication, procurement and facility lifecycle (Eastman et al. 2008).

BIM FM: The integration of Building Information Modeling during the facility management phase.

Facility Management: A profession that encompasses multiple disciplines such as electrical, mechanical and plumbing to ensure functionality of the built environment by integrating people, place, process, and technology (International Facility Management Association 2013).

Safety Culture: The product of individual and group values, attitudes, and behavior that determine the commitment to health and safety (International Nuclear Safety Advisory Group 1992).

Safety Protocol: Steps to mitigate health hazards in order to safely execute a facility management task.

Appendix B: FACE Report Data Collection and Analysis Spreadsheets – Falls

NIOSH FATALITY REPORT DETAILS
Falls

FACE Report No.	Summary of Incident	Fatality Type	Type of Maintenance	Procedural Failure	FM Worker Detail	Experience Level	Asset	Environment	Asset	Environment	Additional Nodes [2]	Hazard(s)	Tools	Hazard Controls
							MAIN NODE DEVELOPMENT		Sub Node Development					
California Case Report 07CA007	Maintenance worker was using a broom to clean debris off of a skylight when the broom snapped causing the worker to fall into the skylight. The skylight collapsed and the worker fell 17 ft.	Fall	Unplanned / Reactive Maintenance	No Fall Arrest System	39 Year Old Male	Inexperienced (6 months)	Floor	Elevated Work Space	Glass / Breakable Material	Outdoor		Fall from Elevation	Ladder	Fall Arrest System
				Tool Failure								Shatter Hazard	Wood Broom	Verify tools are in good working condition
												Worn / Broken Tools		Make asset information accessible (i.e. skylight breaking point)
FACE Report No. 9013	12ft. Fall from scaffolding while removing asbestos contaminated insulation. A single piece of 2inx12in wood was used in lieu of decking. Wood was not fastened correctly and slip, causing the victim to fall from the scaffolding.	Fall	Planned Repair	No Fall Arrest System (required on scaffolding above 10ft)	21 Year Old Male	Inexperienced (1 month)	Lift System (Scaffold)	Elevated Work Space		Indoor		Fall from Elevation	Scaffold	Fall Arrest System
				Improperly erected scaffolding										Scaffold Installation 29 CFR 1910.28 (1)
														Decking Installation 1926.451 (2)
Massachusetts No. 11-MA-008-01	Painter falls two stories from mobile tubular scaffolding in a school lobby. Unwitnessed. School was unaware that painting was taking place on Sunday. No owner's manual for scaffolding or applicable training. Only 2 of the 4 wheels were locked.	Fall	Planned Repair	No Fall Arrest System (required on scaffolding above 10ft)	69 Year Old Male	Experienced (27 Years)	Lift System (Scaffold)	Elevated Work Space		Indoor		Fall from Elevation	Mobile Scaffold	Fall Arrest System
				Improperly erected scaffolding										Scaffold Installation 29 CFR 1910.28 (1)
														Decking Installation 1926.451 (2)
FACE Report No. 9801	Maintenance manager falls 7' off of improperly secured safety platform elevated by a forklift. Changing lightbulb. Victim shifted his weight and toppled the platform. Fell and platform struck the worker.	Fall	Unplanned / Reactive Maintenance	Improperly secured safety platform	61 Year Old Male	Experienced (5 Years)	Lift System (Safety Platform)	Elevated Work Space		Indoor	Aerial Lifts	Fall from Elevation	Safety Platform	Workers were informed of platform and forklift safety, but did not check.
													Forklift	Safety Platform 29 CFR 1910.178 (m) (12) (i)

FACE Report No. 9104	Maintenance worker falls 7ft. into sawdust storage silo and suffocated. Victim's upper half became submerged in sawdust and died.	Fall / Exposure to Harm (Asphyxiation)	Planned Maintenance	No Safety Belt (working above stored materials)	52 Year Old Male	Experienced (8 Years)	Top Access Structures	Elevated Work Space / Particulate		Unknown		Fall from Elevation / Fall into hazardous environment	Rake	Fall Arrest System / Working above loose or granulated stored materials 29 CFR 1926.250 (b) (2)
Michigan FACE Report No. 10MI006	Maintenance supervisor fall off ladder and fell down stairs while changing a light bulb. Victim rested a closed 8 foot ladder against a 42" knee wall to reach a light placed above the second floor landing.	Fall	Unplanned / Reactive Maintenance	Improperly secured ladder / No Health and Safety Plan	66 Year Old Male	Experienced (11 Years)	Working on a Ledge / Landing	Elevated Work Space	Electrified Equipment	Indoor		Fall from Elevation	Ladder	Proper training for appropriate ladder usage
NY FACE Report 07NY080	Maintenance worker fell when a aerial work platform collapsed while installing a sign approx. 35 feet in the air. Investigation showed the lift system had been improperly modified (unauthorized) and failed where the mod took place.	Fall	Planned Maintenance	Improperly Modified Equipment	54 Year Old Male	Experienced (5 Years)	Lift System Failure (unauthorized modification)	Elevated Work Space		Outdoor		Fall from Elevation	Aerial Lift	Verify tools are in good working condition
FACE Report 9621	A roof laborer fell through a roof opening while repairing a damaged membrane. Victim disconnected his lanyard and stepped on an exposed ceiling tile. The tile gave away and the victim fell 90 feet.	Fall	Unplanned / Reactive Maintenance	Disconnected Lanyard	27 Year Old Male	Inexperienced (1 Day)	Floor	Elevated Work Space		Outdoor		Fall from Elevation		Convey the importance of maintaining fall arrest protection at all times

| Texas FACE Report 98TX13301 | A maintenance worker fell through a skylight while walking across a roof. The victim was changing light bulbs on the side of a building. The victim crossed the roof to get to the other side of the building, stepped on a skylight, and fell 16 feet. | Fall | Planned Maintenance | No Fall Arrest System / Improper barricading of potential hazards | 48 Year Old Male | Trained (1 Year) | Floor | Elevated Work Space | Glass / Breakable Material | Outdoor | | Fall from Elevation / Shatter Hazard | Lift System | Fall Arrest System / Make asset information accessible (i.e. skylight breaking point) |
| FACE Report 9506 | A painter fell from improperly secured tubular scaffolding while painting roof eaves. The scaffolding was not equipped with side rails and only utilized 2 12" x 6' unsecured boards as a floor, covering only about 2/3 of floor area. Victim misstepped and fell 35' off the side of the scaffold. | Fall | Planned Maintenance | No Fall Arrest System (required on scaffolding above 10ft) / Improperly erected scaffolding | 60 Year Old Male | Experienced (20 years) | Lift System (Scaffold) | Elevated Work Space | | Outdoor | | Fall from Elevation | Scaffold | Fall Arrest System / Scaffold Installation 29 CFR 1910.28 (1) / Decking Installation 1926.451 (2) |

[1] Maintenance Requires Entrance (MRE) - A worker must enter the asset or place their body within the bounds of the asset to complete repair or maintenance activity.
[2] Additional Nodes - Nodes that are not directly related to the FACE report but are extrapolated based on similarity or opposition to item in FACE Report.
[3] Hazard Communication Program - A set of protocols to enact in the event of an emergency.

Appendix C: FACE Report Data Collection and Analysis Spreadsheets – Contact With / Struck By

NIOSH FATALITY REPORT DETAILS
Contact With / Struck By

FACE Report No.	Summary of Incident	Fatality Type	Type of Maintenance	Procedural Failure	FM Worker Detail	MAIN NODE DEVELOPMENT			Sub Node Development		Additional Nodes	Hazard(s)	Tools	Hazard Controls
						Experience Level	Asset	Environment	Asset	Environment	(Switch, Lever, Press)			
FACE 9717 In-House	Maintenance Electrician is crushed between a nip barrier and the upper frame of a paper rewinder after manually engaging a limit switch. Task was to replace limit switch arm.	Contact With / Struck By	Unplanned / Reactive Maintenance	Lockout / Tagout	37 Year Old Male	Seasoned/Expert - 8 Years	Automated Motion; Maintenance Requires Entrance (MRE)	Elevated Work Space	Sensory Automation (Limit Switch)	Lift System	Manual Automation (Switch, Lever, Press); Manual Override	Hazardous Energy; Pinch Points; Sensory Automation (Limit Switch)	8ft Fiberglass Step Ladder; Screwdriver	Lockout / Tagout Automated Equipment; Penalty for not adhering to procedures
Oregon FACE Report 04OR003	A maintenance millwright was grinding the teeth on a debarker when he was crushed by a press roll when an employee in a different area of the plant, shut off the air compression system. The press was held in place by the air compression and a pin locking system. Although the equipment was deenergized, the pin system was not placed to hold the press in place in the event of air pressure drop. Once the air compression dropped below the weight that was holding the press in place, the press came down and crushed the millworker who was positioned under the press working on the debarker.	Contact With / Struck By	Planned Maintenance	Lockout / Tagout; System wide shutdowns should be coordinated - Notification of maintenance in the area	24 Year Old Male	Trained - 3 Years	MRE; Automated Motion	Grade	System wide shutdown capability			Pinch Points; System Wide Shutdown	N/A	Verify ALL lockout/tagout procedures are completed; System wide shutdowns should require system check for other activities that may be affected
Oregon FACE Report 05OR008	A maintenance mechanic was verify the proper function of a newly installed chain on a "staker." The mechanic did not notify anyone he was down in the restricted part of the machine, while the machine was being utilized by workers. The mechanic apparently entered the area while the machine was in idle as the operator was loading in more material for the staker, pulling the machine out of idle and continuing to work until someone noticed the mechanic on his back in the restricted area. It appears the traveling bar that moves the staker crushed the mechanics head against a horizontal beam.	Contact With / Struck By	Planned Maintenance - Inspecting new equipment	Lockout / Tagout; Improper notification to operator - Notification of maintenance in the area	55 Year Old Male	Seasoned/Expert - 5 Years	MRE - Not visible from operator station; Manual Automation	Grade; Inside Equipment				Pinch Points; Hazardous Energy; Non visible areas from operator booth		Inspections should always require shutdown procedures prior to work; Communication procedures for working in operating areas
California FACE Report 00CA007	Maintenance electrician is crushed between the guardrail of a workbasket and the face of an industrial neon-fluorescent sign. Working on a truckmounted hydraulic/electric crane w/ joystick controls, the victim was attempting to replace bulb on a neon-fluorescent sign. While moving a piece into place the joystick were accidentally activated, moving the bucket against the sign and crushing the worker. When a co-worker identified the issue, he did not properly utilize the override controls and was unable to relieve the pressure that was crushing the victim.	Contact With / Struck By	Reactive maintenance	Improper knowledge of override controls to workbasket	32 Year Old Male	Expert - 12 Years	Manual Automation	Elevated workspace - 12 feet	Truck Mounted workbasket with joystick controls			Pinch Points		Workers should be aware of override procedures to mechanical equipment and rescue procedures
New York FACE Report 02NY096	A maintenance worker was cleaning the inside of a dough cutting machine when the system was activated by a co-worker. The steps to place the machine in proper maintenance order was not follwed and when the coworker started up the machine to continue to the maintenance work, the inappropriate lockout/tagout procedure led to the dough cutting blades to activate and partially decapitate a worker cleaning near the blade	Contact With / Struck By	Planned Maintenance	Lockout/Tagout Procedures	54 Year Old Male	Trained - 2 Years	Automated Motion; MRE	Inside cutting equipment				Hazardous Energy; Dangerous Equipment		Lockout / Tagout Automated Equipment is properly completed
California FACE Report 98CA004	A maintenance worker was inside of a feather drying mechanism performing weekly cleaning. Without properly LO/TO the equipment, a coworker initiated the system, not knowing the worker was in the paddle drying machinary, starting the drying paddles and crushing the maintenance worker.	Contact With / Struck By	Planned Maintenance	No LO/TO procedures; No training on equipment dangers; Notification of maintenance in the area	39 Year Old Male	Trained - 2.5 Years	MRE; Automated Motion	In a Tank	Manual Startup			Hazardous Energy; Dangerous Equipment	`	Lockout / Tagout Procedures; Communication procedures for working in operating areas

Report	Description	Event Type	Maintenance Type	Cause	Age/Gender	Experience	Hazard (red)	Condition (grey)				Hazard Detail		Procedure
California FACE Report 00CA009	A maintenance worker received a fatal blow to the chest while removing a jammed piece of metal from a punch assembly. The punch was not locked out/tagged out and the procedures for removing jammed material was disregarded. It is speculated that after the jam was removed the punch operated and a piece of metal was ejected into the victims chest, causing a fatal wound.	Contact With / Struck By	Reactive maintenance	Disregarded procedures for removing jammed equipment (Improper knowledge of equipment) Lockout/Tagout Procedures	44 Year Old Male	Expert - 15 Years (15 with current employer)	Automated Motion	Grade				Dangerous Equipment - Projectile Potential Automated Equipment		Lockout / Tagout Procedures Equipment specific procedures
Virginia FACE Report No. 9239	A maintenance worker was sucked into a prositive pressure vaccum pipe at a paper processing plant while installing a replacement blower. During the replacement the vitim walked in front of an active suction pipe and was sucked in by the 3,740 psi vacuum pressure. The victim died of massive trauma	Contact With / Struck By - Sucked into pipe	Reactive maintenance	Improper training and documentation of equipment specific hazards (Improper knowledge of equipment)	38 Year Old Male	Unknown	Vacuum Suction	Exposed Vacuum area during maintenance				Hazardous Energy		Equipment specific procedures

Report	Description	Event Type	Maintenance Type	Cause	Age/Gender	Experience	Hazard (red)	Condition (grey)				Hazard Detail		Procedure
FACE Report No. 2002-05	Two maintenance worker changed the control valve on a air pressured pneumatic valve that operated a 2,000 pound door on a vacuum cooler. The victim wanted to verify the system was functioning properly after the installation by partially raising the door and placing his body within the doors threshold. An airline blew off the system, causing the door to close on the victim, crushing him.	Contact With/Struck By	Reactive maintenance	Improper use of Standard Operating Procedures	37 Year Old Male	Expert - 18 Years	Automated Motion	Grade				Pinch Points		Improper use of Standard Operating Procedures
FACE Report No. 2006-02	A maintenance worker was pinned between feed rolls of a debarker while welding additional metal to the feed roll teeth. Although the victim had lockedout/tagged out some of the equipment, not all of the electrical disconnects were lockedout and the air line to the machine had not been shut off. The victim placed his head between upper and lower feed rolls, the air pressure on the rolls automatically cycled and closed on the victim's head	Contact With/Struck By	Planned Maintenance	Lockout/Tagout Procedures	52 Year Old Male	Trained - 2 Years	Automated Motion MRE	Grade				Pinch Points Hazardous Energy		Lockout / Tagout Automated Equipment is properly completed

Appendix D: FACE Report Data Collection and Analysis Spreadsheets – Non Elec. H.E&S.

NIOSH FATALITY REPORT DETAILS
Harmful Environments and Substances - Non Electrical

FACE Report No.	Summary of Incident	Fatality Type	Type of Maintenance	Procedural Failure	FM Worker Detail	Experience Level	Main Node Development Asset	Main Node Development Environment	Sub Node Development Asset	Sub Node Development Environment	Additional Nodes [2]	Hazard(s)	Tools	Hazard Controls
California FACE Report 11CA008	Two Maintenance Workers were tasked with cleaning out a drainage system that sits beneath an organic waste composting area. First attempts to clean the drainage systems from grade failed, the workers entered the drainage pit, and died due to hydrogen sulfide asphyxiation.	Exposure to Harm (Asphxiation) - H Sulfide	Planned / Annual Maintenance	Confined Space Protocol	16 Year Old Male (Showed documentation being 30 at time of hire) & 22 Year old Male (brother)	Inexperienced (3 months)	Manhole	Confined Space				Hydrogen Sulfide	Ladder	Confined Space Protocol (Air Monitoring, SCBA, Safety Line)
				Hazard Communication Program [1]			MH E	Toxic Environment					High Pressure Hose	Hazard Communication Program
														Verify skill level and training prior to FM task
FACE Report No. 9104	Maintenance worker falls 7ft. into sawdust storage silo and suffocated. Victim's upper half became submerged in sawdust and died.	Fall	Planned Maintenance	No Safety Belt (working above stored materials)	52 Year Old Male	Experienced (8 Years)	Sawdust Silo	Elevated Work Space		Top Access Structures		Fall from Elevation	Rake	Fall Arrest System
		Exposure to Harm (Asphxiation) - Submerged						Particulate				Fall into hazardous environment		Working above loose or granulated stored materials 29 CFR 1926.250 (b) (2)
FACE Report No. 9014	Maintenance worker drowns when inflatable plug gave way and 6 foot diameter pipe flooded. Worker removed respirator and well atmosphere was not tested.	Exposure to Harm - Submerged	Planned Maintenance	Poorly Installed Plug, Removal of Respirator, No Confined Space Rescue Procedures	35 Year Old Male	Inexperienced (11 months)	Large Diameter (6ft) Pipe	Confined Space				Confined Space	N/A	Proper respiratory training according to CFR 1910.134(a)(3)
								Water Structure				Flooding Hazard/Drowning Hazard		Employee did not ensure that inflatable valve was installed per Manu. recommendations. 1) Clean out pipe prior to installation 2) Plug should be installed with a back up system (i.e. gate valve) 3) Plug should be anchored in place 4) Ensure inflated to 30 PSI
														Prepare Confined Space Rescue Procedures
FACE Report No. 8928	Two maintenance workers died of hydrogen sulfied anoxia when entering a manhold to fix an overflow pipe. The initial victim lost consciousness and fell into wastewater. The secondary victim attempted a rescue and also became overcome with H-Sulfide. Rescure attempts by personnel also created H-sulfide illness	Exposure to Harm (Asphxiation) - H Sulfide	Reactive Maintenance (Fixing a broken overflow pipe in a manhole)	No respirators worn during or harness/rescure procedure utilized	Initial Victim - 29 Year Old; Secondary Victim (rescue attempt) - 43 Year Old Male	Trained - 4 Years & Experienced - 6 Years	Manhole	Confined Space				Hydrogen Sulfide	N/A	None of the procedures in place were executed
							MH E	Toxic Environment						
								Water Structure				Flooding Hazard/Drowning Hazard		Confined Space Protocol (Air Monitoring, SCBA, Safety Line)
Colorado FACE Report 91CO074	Two maintenance workers entered a vault to clean a bar screen. After rescuing a co-worker who passed out, the rescurer was overcome with H-Sulfide and collapsed in the vault.	Exposure to Harm (Asphxiation) - H Sulfide	Preventative Maintenance	No respirators worn during or harness/rescure procedure utilized	49 Year Old Male	Inexperienced - No Training Program Available (2 Years)	Manhole	Confined Space				Hydrogen Sulfide	N/A	Appropriately Train Staff
							MH E	Toxic Environment						Confined Space Protocol (Air Monitoring, SCBA, Safety Line)
Oregon FACE Report 04OR037	A janitor using a propane powered buffer was overcome with carbon dioxide. The worker was unaware that the propane buffer was producing high levels of CO and propane exhaust. No doors or windows were used for ventilation	Exposure to Harm (Asphxiation) - Carbon Monoxide	Preventative Maintenance	Improper Ventilation	50 Year Old Male	No Training (2.5 weeks)	Dangerous Exhaust Producing Equipment	Improperly Ventilated Space					Propane Powered Buffer	Appropriately Train Staff
								Equipment producing far more CO ppm than OSHA allows						Ventilate Space when working with equipment producing exhaust
														Verify equipment is working as intended
														Add air monitoring for equipment producing exhaust
Alaska FACE Report 91-13	Three maintenance workers entered a room with self closing doors to fix a refrigerant leak from a damaged pipe at an ice rink compressor room. Two men were found and resuscitated, but rescuers were unaware of the third victim who was out of sight.	Exposure to Harm (Asphxiation) - Oxygen Deficient (displacement) due to CFC-22	Reactive Maintenance (Fixing a broken refrigerant line)	Incorrect repirators were worn. Victims wore air purifying respirators which are not appropriate for oxygen deficient environments	24 Year Old Male	Inexperienced - No Training - Monthly safety meetings but no written plans or work procedures	Refrigerant Leak (CFC 22) from damaged pipe	Oxygen Deficient Environment due to CFC-22	Refrigerant leaked into adjacent room when doors were opened causing illness to EMS personnel who were not wearing SCBA			Oxygen Deficient Environment due to CFC-22	Damaged Refrigerant Compressor	Verify appropriate equipment for maintenance task
														A number of requirements, including air monitoring should be available outside of the room. SEE FACE Report for requirements
														Emergency plan for specilized areas
														Appropriate training needs to be executed especially with equipment producing toxic gas

NIOSH publications 80-106, "Working in Confined Spaces," and 87-113, "A Guide to Safety in Confined Spaces."

Appendix E: FACE Report Data Collection and Analysis Spreadsheets – Electrical H.E.&S.

NIOSH FATALITY REPORT DETAILS
Harmful Environments and Substances - Electrical

FACE Report No.	Summary of Incident	Fatality Type	Type of Maintenance	Procedural Failure	FM Worker Detail	MAIN NODE DEVELOPMENT Experience Level	Asset	Environment	Sub Node Development Asset	Environment	Additional Nodes	Hazard(s)	Tools	Hazard Controls
Washington Case Report 04WA080	Maintenance Worker was changing a broken metal halide bulb in a ceiling fixture. The worker shut down the breaker but was unaware that the fixture was part of the building emergency lighting system and was on a separate circuit.	Exposure to Harm (Electrocution)	Reactive Maintenance	Lockout / Tagout; Unqualified Worker; System Verification Omitted	32 Year Old Male	Inexperienced - 5 Months w/o electrical experience	Electrified Equipment	Elevated Work Space	Power Source Shutdown	Attic Space		Hazardous Energy; Heat / Burns	Ladder; Non-Insulated Hand Tool	Verify skill level and training prior to FM task; Lockout / Tagout Electrified Equipment; Test all circuits to verify hazardous energy has been shutdown prior to FM Task.
FACE Report No. 88-21	A maintenance worker was replacing a suction hose on a 440-volt electric motor. After replacing the hose, he asked a co-worker to energize the gear that was shut down in order to test the hose for leaks. The workers hand was resting on a conductor that that wasn't covered because the junction box cover that was supply the motor was not replaced. With his hand on the conductor and his stomach on the metal frame of the machinary, he recieved a shock and died	Exposure to Harm (Electrocution)	Preventative Maintenance - New installation	No developed step by step procedure from company; Unqualified Worker; Energizing gear protocol	20 Year Old Male	Inexperience - Trainee - Employed for 2 months	Electrified Equipment	Slightly Elevated - 3 Foot Buggy				Hazardous Energy	3 Foot Buggy	Verify skill level and training prior to FM task; Create step by step instructions for energizing equipment
FACE Report No. 8610	While cleaning five circuits, roughly 40 ft above the ground at a large utility substation. While cleaning a deenergized circuit, the victim reached across a closed circuit and essentially provided a conduit for static build up to travel from one conductor to the next. He received 20,000 volts and fell 40 feet from the lift. The medical examiner noted that the cause of death was the fall, not necessarily the shock	Exposure to Harm (Electrocution) - Caused fatal fall	Preventative Maintenance	Lockout/Tagout Procedure; Improper Harnessing	33 Year Old Male	Experienced - 5.5 years of substation training. Almost journeyman status	Electrified Equipment	Elevated Work Space				Hazardous Energy; Fall from Elevation	Aerial Bucket	Lockout / Tagout Electrified Equipment; Harness Requirements for elevated work
California FACE Report 06CA008	An inexperienced worker was told by his maintenance supervisor to "check out" why the garage area of the hotel lost power. The worker was not qualified, opened the panel, and touched a live fuse. The worker was on the phone with his supervisor, who told him not to touch the fuses when the incident occured. It is likely the worker did not know what a fuse looked like.	Exposure to Harm (Electrocution)	Reactive Maintenance	Inexperienced Worker; Lockout/Tagout Procedure	39 Year Old Male	Inexperience - Not qualified for electrical work - 3 months with hotel	Electrified Equipment	At grade				Hazardous Energy	N/A	Verify skill level and training prior to FM task
FACE Report 89-18	A victim did not follow the appropriate "captive key" procedures in order to de-energize high voltage gear. A captive key requires a number of steps to obtain the correct keys in order to appropriate lockout/tagout. The process is intended to not allow staff to forget a step. The worker knew that the hatch to enter the facility was broken and therefore did not complete the captive key procedure (executed 3 of 6). As he entered the cabinet, he came in contact with a 50,000 volt conductor	Exposure to Harm (Electrocution)	Preventative maintenance - Annual shutdown - Workers maintain 12 hour, 7 day a week work days for extended period until annual shutdown is complete	Procedural Failure; Broken safety equipment - Equipment had been noted as broken 7 days before the incident	39 Year Old Male	Experienced Journeyman - 12 years	Electrified Equipment	At grade	Energized Area			Hazardous Energy	N/A	Verify safety equipment is in working condition; Stress the importance of lockout/tagout procedures
FACE Report 91-32	While performing refrigeration maintenance on a walk-in cooler at a restaurant. The flexible metal conduit housing the power conductors to the refrigeration unit (RU) of the cooler had been designed to serve as the mechanical ground. The insulation on one of the three power conductors in the flexible conduit was damaged and allowed electrical arcing to s conduit connector on the RU starter box (Figure). The conduit connection to the RU starter box (from the RU) was loose, and effectively disconnected the mechanical ground from the RU. As the victim was servicing the RU, the temperatures in the walk-in cooler must have caused the thermostat to close the starter, energizing the surface of the RU, and fatally shocking the technician when he touched it.	Exposure to Harm (Electrocution)	Reactive Maintenance	Lockout / Tagout; Damaged Equipment	33 Year Old Male	Trained - At least two years, Associates degree in HVACR	Electrified Equipment	At grade, but taller equipment				Hazardous Energy	N/A	Improper Lockout/Tagout; Check for damaged lines or equipment prior to maintenance work
FACE Report 89-19	A maintenance worker electrocuted when he inadvertently touched an exposed wire on a flexible conduit that had been worn down by a repeatative rubbing against a spool piece. The flexible conduit served as the power shutdown (plug) to the meat packing equipment. The maintenance staff would unplug this equipment each day. Because the conduit was damaged and had not been unplugged yet, the worker was electrocuted	Exposure to Harm (Electrocution)	Preventative maintenance	Damaged Equipment - Exposed wiring	37 Year Old Male	Experienced - 4 year vocational, lots of additional work expereience - 3 months with company	Electrified Equipment	At grade				Hazardous Energy		Check for damaged lines or equipment prior to maintenance work

Appendix F: Data Collection Interview Questions

1. What is your current position?
   a. What type of activities do you execute on a daily basis?
   b. Do you manage any staff? If so, how many?

2. What type of safety training is done within your company for new and existing employees?
   a. How often, how long, what type (videos, teachers, modules, etc.)
   b. New vs. existing employees
   c. Specific training for certain operations (i.e. Arc flash)
   d. OSHA training?

3. Is this method of safety training effective AND is there a method of measuring effectiveness?

4. How is Operations and Maintenance data transferred from construction activities to the facility management staff at the completion of a project?

5. What is the step-by-step process for initiating an FM task at your company?
   a. Does the process vary between a preventative or reactive task?
   b. What software is utilized in your company for FM tasks? This includes models, work orders, document management, etc.
   c. What process is used to identify the equipment that requires maintenance? For example – reference the drawings and specs, look at a 3D model, visit the piece or equipment.
   d. Are tasks generally executed by a single person or a team?
      i. If given to a single person, do safety protocols shift?

6. Where is safety relevant information stored and how is it referenced prior to an FM task?

7. When working at elevation, what are the safety considerations that need to be made?
   a. What about in regards to lifting systems, i.e. ladders, scaffolding, buckets, etc.

8. When working in a confined space or toxic environment, what are the safety considerations that need to be made?
   a. Is air monitoring utilized?
   b. Is there a difference between working in a pipe vs. a manhole vs. a tank?

9. When working with electrified equipment, what are the safety considerations that need to be made?
   a. Is there specialized equipment or PPE?
   b. What are the training or certification requirements to do electrical work?
   c. Is there a difference between working on gear that has high voltage (600v+) than low voltage (<600V)

10. When working with automated equipment, what are the safety considerations that need to be made?

11. How do multiple safety concerns (i.e. working on electrified equipment at elevation) effect the safety preparation of the FM task?
    a. Can you think of any other special scenarios that require additional/exceptional safety preparation?

12. In your experience can you provide an example of an accident and why it happened?

       a. How could it have been mitigated?

13. How does age, weather, experience, or any other factors impact the way FM tasks are approached?

14. Provide scenario and ask for input

15. Is there anything you wish you were asked in this interview that was not mentioned or wish to share?

Appendix G: Data Collection Interview & Analysis Spreadsheets – Sally

	Sally
Job Title	Safety Manager for Facilities Management -- Large University, Southeastern Region USA
Job Responsibilities	...schedule safety inspections, program manage meetings, mm, working on safety programs either revising or completely creating and and being everyone's mothers what I like to call the safety managers uh, we, you know, I'm out there and I'm really working the guys on projects and and working on the constructions sites. We have small constructions sites that we manage, we have large construction sites that we're program management but other companies are actually doing the construction...
Staff Size	Five Hundred Employees (50 in management, 50-75 in management design, remaining maintenance)
Training (New Employee)	A new employee gets a bare minimum depending on their job description. Its emergency management, active shooter which is very big these days uh, they'll get defensive driving, their fleet management, those are the basics four and then it expands on from there. Will they be working at heights, then we have to work on the fall protection, man lift training, will they be going into confined spaces, do they need electrical safety, what, what do they need for their job and then we we try to pull it out of specials...
Training (Existing Employee)	A minimum of one session a month and we require each shop to do a five minute session every week and I provide all that information for five minute sessions and conduct the majority of the monthly sessions.
Software	AssetWorks AIM
Safety Info in Work Order	...there now is a a small little note section where they can actually put in safety notes for their employees. They say oh by the way you need to wear, now don't forget to wear your full face shield and your spagoles with this one...So their putting in their PPE requirements in as they go, or supposed to be... [Executed by] the supervisor
Safety Info Storage	If someone needed to gain access to a safety protocol or program, we have our safety intranet on Sharepoint. That has all the current programs that are in place, any documentation they may need, training pieces they may need, its there. Guidelines, things like that...Every personnel in the facilities has access.

	Sally	Safety Codes
Falls	[MAN POWER REQUIREMENT - PROTOCOL] ...if their working at heights, usually there's more than two people. There's going to be at least one person on the ground, one person up high, usually two people on the ground.	PROTOCOL: 2 people when working at heights
	[FALLS PROCEDURE] ...they're gonna have to look first of all and figure out what piece of equipment do they need. Do they need a man lift, do they need a nifty lift, do they need the eighty foot lift or can they do it all from a ladder. If they can do it from a ladder, which ladder is appropriate. We've had some issues with this is in the past but they've got better ladders now. And they can actually, some of them actually have cages on top of them where they can get out and work on the top of the ladder instead of having to pull a lift over.	PROTOCOL: Lift System ATTRIBUTE: Working Height
	[LIFT SYSTEM - BUCKET TRUCK PROTOCOL] ...if they're having to use a lift they know they have to have fall protection training and they have to have training in how to operate that lift. Both of which is about 12 hours of the training right there. So, they're getting that and they know if they have the training or they don't have the training.	PROTOCOL: Lift System - Bucket Truck
	[HARNESS SAFETY] They won't have a safety harness if they don't have the training.	PROTOCOL: Fall Arrest System
	[LIFT SYSTEM - BUCKET TRUCK] ...a lot of their work is gonna be done from the bucket truck and they are always tied off in the bucket truck.	PROTOCOL: Lift System - Bucket Truck - Fall Arrest System
	[LIFT SYSTEM - BUCKET TRUCK] ...miles per hour is going to based on what the bucket truck can handle or the manlift can handle at this point about 25 miles per hour and we look at the airport numbers, twenty-five miles per hour is pretty darn high winds and we'll probably shut it down at more like fifteen because the guys are so uncomfortable being up there	PROTOCOL: Lift System - Bucket Truck
	[FALL ANCHOR POINTS] ...we don't know where (the fall anchor points) are on all our buildings; maybe all our buildings don't have them cause their all so old. And since we're a Non-OSHA state we have to fight to get those things put in place.	ATTRIBUTE: Anchor Points (Y/N)

	Sally	Safety Codes
Hazardous Environment - Electrical	[MAN POWER REQUIREMENT - PROTOCOL] Electricians can work by themselves depending on what they are doing. If their doing an assessment, their documenting information, they are making a change in a light bulb, yes, they can do that by themselves. Most of the time our electricians are in pairs.	PROTOCOL: 1 person for investigation and simple tasks; 2 people for more difficult tasks
	[LO/TO SAFETY] Same with lockout/tagout, you don't get your lock unless you have the training	PROTOCOL: Lockout/Tagout
	[PROTOCOL - STEP BY STEP] First and foremost, they are going to look at the plans if they don't know where the line feeds already are and they are going to do every, to make every effort to shut it down and make sure that it's lockedout/tagged out and dead prior to them working on it.	PROTOCOL: Lockout/Tagout ATTRIBUTE: Disconnect Location
	[PROTOCOL - HOT WORK] ...they have their processes that are not allowed to work on something um, that's live unless they have two people, we have all the arc equipment, arc flash equipment that they need to have. We have several live work programs in place	PROTOCOL: Hotwork - Equipment PROTOCOL: Hotwork - 2 people
	[PROTOCOL - HOT WORK PPE] ...it's their face shield, their tested gloves, their over shirts if they have to have or over shirts, the uniforms for the personnel who are affected by it are automatically a level two arc flash but there are times when they may have to go over and above that or they have a short-sleeved and they need to have the long-sleeved on. So, they now have all that gear with them, and the hard hats, the safety glasses, the hearing protection	PROTOCOL: Hotwork - Equipment
	[PROTOCOL - HOT WORK BARRICADING] ...it's in an area where they can't just kinda shut the door then they have to have, you know, the blocking, they have to have someone blocking it off for them and assuring they have the correct um, distances	PROTOCOL: Hotwork - Barricading

	Sally	Safety Codes
Hazardous Environment - Confined Space/Toxic Environment	[CONFINED SPACE MONITORING] ...we just bought brand new monitors, everyone's been trained on how to use those monitors and we monitor not every 10 minutes, we monitor continuously, that way we know if when they're cleaning a storm drain, you know, are they picking up something that, you know, was a pocket and that we didn't know what was in there.	PROTOCOL: Confined Space - Air Monitoring
	[TOXIC ENVIRONMENT - PROTOCOL] We will have to shut it off remotely prior being able to go in, we'll have to ventilate it out if we can ventilate out. If we cannot access it without respirators and you just walk in there normally being able to breathe it, we will not go in; we'll have to call a contractor in...We don't have, our guys are not, at this point in time, trained on how to use self contained breathing apparatus or trained on how to use, um, like an air line	PROTOCOL: Toxic Environment - Procedure
	[CONFINED SPACE PROTOCOL - STEP BY STEP] We, first of all, have to determine where it is. We may have to shut down a parking lot or road to access these, may have to shut down a pedway, um, to access this. So, we have to do all our outages, so it's part of that preplanning stage. Plan your work, work your plan. Then they'll get, they'll gather all the employees, there are a lot actually work in a confined space, I will not allow anyone who's not had the training even be on the site. Gather their equipment, make sure all their equipment's functioning properly and then they can do their entry permits and work in the hole.	ATTRIBUTE: Valve Location
	[CONFINED SPACE TRAINING] All the person's entering a confined space will be confined space trained	PROTOCOL: Confined Space

	Sally	Safety Codes
Contact With / Struck By	[AUTOMATED EQUIPMENT - LO/TO] We are constantly doing the lockout/tagout of HVAC systems for that because those are all automated	ATTRIBUTE: Automated Equipment PROTOCOL: Lockout/Tagout
	[AUTOMATED EQUIPMENT - SECONDARY LO/TO] We also have what I call lockout tagout caution. Where you are taking a system and putting it down to say twenty percent to change filters out. We have the tag system for that to notify personnel that may be working behind someone that hey, don't mess with this system it's down to fifty percent for this reason. Until we have thing we have a yellow tag that we use, very similar to the lockout tagout but it's not necessarily locked out its just caution tagged out.	PROTOCOL: Lockout/Tagout

	Sally	Safety Codes
Dual Processes	[CONFINED SPACE AND ELECTRICAL] ...significant amount of underground electrical equipment and they are constantly entering manholes vaults and having to run a brand new feed for our stadium or, you know, to feed that side of the campus to that switch and they do have those considerations, there both considerations. First and foremost, you have to start the confined space process but when you are in a situation like that	FRAMEWORK: Dual Process Concern
	[CONFINED SPACE AND ELECTRICAL - STEP BY STEP] You have to look at the main hazards. You're not affected initially by the electrical; you're affected by the confined space. You start that first and you have that process running and then you go and do your electrical work. And then you're backing in and you're backing out. You're always in a confined space and then you have that, to top it off, you could die when you're in that confined space because of the electrical hazards.	FRAMEWORK: Dual Process Concern
	[EXCAVATION AND ELECTRICAL] ...anyone such as our electrical distribution who may have need to enter an excavation, will have excavation safety, as well as confined space, as well as all the other training they need to do their job. Whether it's up high at heights and they have to use their man buckets or their lift truck or it's down on the ground.	FRAMEWORK: Dual Process Concern
	[CATWALK AND ELECTRICAL] ...we're looking at something like a catwalk.. we're not really looking at, if you're hit you're gonna (fall), you're probably more likely to energize that catwalk and that is going to be a major hazard there (so the energization of the catwalk is more of a concern than the fall).	FRAMEWORK: Dual Process Concern

	Sally	Safety Codes
Outside Factors to Safety - Environment	[HEAT STRESS] The biggest hazard we have here is not necessarily the electrical work because I have 100% trust in my guys that they can do that right. It's the outside factors like heat stress... Can I make it through and do this work and still be coherent enough to not pass out from the heat and then we do have an issue with someone either slumping in or falling out of the bucket. And we've had that	PROTOCOL: Outdoor Environment: Heat Stress
	[HEAT STRESS] As for temperature wise it's really more of what can they handle, have they been able to handle that, are they acclimatized to it, have they been drinking the water, the Gatorade and eating well or have they not and that's a personal and it's also a kind of a you're your brother's keeper	PROTOCOL: Outdoor Environment: Heat Stress

160

Appendix H: Data Collection Interview & Analysis Spreadsheets – Bill & Chris

	Chris	Bill
Job Title	Director of Utilities and Energy	Assistant Director of Utilities and Energy
Job Responsibilities	...responsible for the utility infrastructure on campus which is high voltage electricity or electrical distribution group. We have a group called Utility Services which handles natural gas, infrastructure, domestic water, sanitary and storm sewer. That group also performs utility locates, meaning they mark utilities for construction projects on campus.we also have a Plant Operations Group, which has, um, three types of plants. There, uh, in charge of along with the associated underground piping, um, they have chilled water, hot water and steam plants. There's nine plants total	But basic, um, so that uh, we're in the operation and maintenance business primarily. So we operate and maintain the plants as Ken was saying and we operate the electric distribution system so we have a crew of people that work um, in the operation of maintenance of electric distribution. The locate folks do locates but also they operate and maintain the gas and water systems. So, their involved with the maintenance activities associated with those tasks. Um, and then I guess the energy management group folks are more of a white collar group but they do get into the field and are exposed to some hazards associated with safety around rotating equipment um, electrical equipment that sort of thing.
Staff Size	30+	30+
Training (New Employee)	...one more thing on the linemen is that training can take up to two years to accomplish. You know, it's not a weeklong thing you go to, come back and you're ready to go.And even at that point you know, they could advance the position their in their job family but to advance to the next level where really the second level it's, they can work independently here, they have to be certified by the supervisor. So there's even, you know it's, as Malcolm indicates it's a very dangerous area of work and so we really take caution and make sure the guys are fully trained. You can understand electricity and how it works but then you have to understand our system before you can work independently.	so since you mentioned the high voltage so, I think there is a differentiation between our high voltage workers, our electrical distribution workers and our others. Um, our electrical distribution workers are required to go through an approved apprenticeship program. It covers safety aspects of job. They're not released as full journeymen workers until they have completed and are certified with that program which includes safety aspects of their job. Yeah, one more thing on the linemen is that training can take up to two years to accomplish. You know, it's not a weeklong thing you go to, come back and you're ready to go.
Training (Existing Employee)		No sir, we use an outside certified training program but before they can advance and before they are cut loose so to speak, um, doing their job they have to have completed that. Uh, formal training.
Software	Share Point	
Safety Info in Work Order	N/A	
Safety Info Storage	N/A	

	Bill and Chris	Safety Codes
Falls	[MANPOWER REQ. - PROTOCOL] ...They also, also make sure that we have somebody ground spotting to make sure that, you know, that you're lifting up that you're not gonna hit another hazard that you don't see. So, try to make sure we have people on the ground watching in case something happens and they can respond quickly but also point out hazards and say...	PROTOCOL: 2 people when working at heights
	[FALL ANCHOR POINTS] ...Making sure you have your harness on, and your, you know, have someplace to attach to. A lot of our plants, you know, will have piping up in the ceiling and making sure that their, you know, can, you know, hook on, to a secure place that's approved. There's been a lot of changes on that the last few years where things that were done in the past and places that we were able to hook to, we're no longer able to hook to because, you know, those structures haven't been able to be load tested.	ATTRIBUTE: Anchor Points

	Bill and Chris	Safety Codes
Hazardous Environment - Electrical	If we de-energize it, we've got a hold order tagout process. We don't use locks we use hold order tags where we tag our points. First of all, we write a switching order to free the line, which is a formal written thing on one sheet that they write down which switches to open to close... The discipline in doing that is very important so they, one man is on the radio saying open that switch, the other guys over there open it, confirm it's open, check it's open visually. So the switching is the first step. They place the tags; they then check the system to make sure it's de-energized. So they use hot sticks, uh, to make sure that there's no voltage present before they, uh, start to work. And the tags prevent anybody from operating, any time a tags on a piece of equipment that prevents it from being operated. So, that's the non-hot work or the de-energized work. On hot line work there's a whole protocol of, you know, gloves, protective equipment, face shields, clothing that our guys wear. You know, arc flash certified electric clothing.	PROTOCOL: Hold Order Tags PROTOCOL: Switching Order PROTOCOL: Hot Sticks PROTOCOL: PPE
	[PPE and MANPOWER REQ.] If their working energized equipment then they have to have on the proper level of personal protection per protective equipment. And um, most, not all of those jobs, most of those jobs are two person jobs.	PROTOCOL: PPE PROTOCOL: 2 People for electrical work
	[HOTSTICKS] Yeah, it's, it's the you always check for voltage before you reach in	PROTOCOL: Hot Sticks
	[SWITICHING ORDER] That individual goes forward and conducts that switching operation. He confirms it specifically by number, by switch then his supervisor repeats back to him what he did and he confirms that so it's a double confirmation. So, it's a pretty detailed confirmation of what switch was operated.	PROTOCOL: Switching Order

	Bill and Chris	Safety Codes
Hazardous Environment - Confined Space/Toxic Environment	[CONFINED SPACE - PROTOCOL] ...So it's not, it's not a uh. We have some, not like confined space obviously requires two people but a lot of jobs that are single person jobs.	PROTOCOL: 2 People when working in confined space
	[VALVE PROTOCOL] So once they hit the site they see where the leak is they start figuring out where to cut the water, what valves, this valve, this valve, this valve. Shut the valves off. Uh, and then it's a matter of getting a, you know, system drained down, the leak located.	PROTOCOL: Valve Shutdown
	[VALVE LOCATION] ...we had several this Spring as a matter of fact when the ground didn't thaw out but it warmed up and caused several lines to break. So, if it's a significant break then we'll isolate the leak before shutting the water off and communicate back that water is being shut off to certain buildings.	ATTRIBUTE: Valve Location
	[TOXIC ENVIRONMENT - AIR MONITORING] ...The plants have, uh, monitors so if there's a leak essentially have evacuation systems in them so but there's nothing tied into if you went out there it's a fairly big space. But then there's pipes low to the ground and the monitor would go off and big fans would start pulling air out	PROTOCOL: Air Monitoring
	[MANHOLE VENTILATION] ...we have a lot of our electrical distribution's underground so there's a lot of electric manholes but, you know, the guys you know, are very well versed in how to handle that. They have, there's, they have the monitors make sure the manholes okay, they have, you know, the air system to make fresh air is being pumped in and um, you know, they'll have somebody on top, you know, while somebody goes down the manhole. Yeah, yeah. That's just a fan that uh. They've got a generator and they got a fan with a piece of duct that they stick into the hole and crank the fan up	PROTOCOL: Manhole Ventilation
	[MANHOLE PROTOCOLS] ...setting up, you know the the trolley up where their lifting, and you know, putting the mechanism to lift, checking the air in the hole with the meter, putting the air, you know, putting the ventilation in the hole that sort of thing	PROTOCOL: Manhole Work

	Bill and Chris	Safety Codes
Contact With / Struck By	[PUBLIC SAFETY - BARRICADING] ...But they make sure that the public is walled off, the students are walled off there's protection of any sort of interference from cars, or students or pedestrian traffic.	PROTOCOL: Barricading
	[AUTOMATED CONTROLS] ...on the plant side, have a lot more of that where it's a lot more automated control cause we, we only staff for basically the first shift and our plants run twenty-four seven.	ATTRIBUTE: Automated Equipment
	[LO/TO] ...we don't have uh broken down by pieces of equipment, you know, how to lock out each type. Essentially, the guys really refer back to just lockout/tagout and try to take all the energy off the equipment which is really comes from, Um, working on the equipment, being familiar with it and knowing where the hazards lie and how to isolate them. So, they uh, they go through a lockout/tagout process but you know, of course, if we don't have a book that has every piece of equipment, how to how to isolate that one specifically.	PROTOCOL: LO/TO
	[TRAFFIC CONTROL] All outside noise and let them focus on the job. Where that means us coordinating traffic control, and getting the barricades put up and the cones. We'll try to do that so our guys can focus on the job and that's where we can help.	PROTOCOL: Traffic Control

	Bill and Chris	Safety Codes
Dual Processes	NONE	

	Bill and Chris	Safety Codes
Outside Factors to Safety - Environment	[MANHOLE VENTILATION] (When pulling in air to a manhole) ...yeah, if you put the fan near the road and the vehicles are going by they'll suck exhaust	PROTOCOL: Special Scenario for roadside manhole ventilation
	[HEAT STRESS] I'll say just this time of year another factor which we've, you know, had some issues with this summer with it being really hot and humid is the conditions.	PROTOCOL: Outdoor Environment: Heat Stress

Appendix I: Data Collection Interview & Analysis Spreadsheets – Joe, Dan, & Tim

	Joe	Dan	Tim
Job Title	Operations Manager	Maintenance Supervisor	Electrician
Job Responsibilities	I manage the entire operations Division. That includes a change over crew which is 5 full time and about 7-8 part-time. Janitorial staff, which is 15 I guess part time. Security staff which is 30-35. Ushers which is probably about 35. Police, fire, and EMS which is unlimited. Two event coordinators which are full time. The maintenance area which has electricians and carpenters. I think that's	*The change over crew following me, the janitors, skate monitors. That's about it right there. I say about 30 people. The janitors, and the night the during and the after crew, change over crew. So about 30 people.*	Maintains electrical needs of the facility
Staff Size	100-150	30	2
Training (New Employee)	Well, the first thing is budgets are limited so that also dictates a lot of what we can do... We do have one annual meeting with all the events staff to go over safety measures, evacuations processes things of that nature. On our full time staff and operations everybody is CPR and first aid certified. They are also certified in driving as far as zambonies, fork lifts, vehicles, things of that nature. We also keep up safety logs for injuries. We also have a safety officer, that's Freddy, that keeps an eye, makes sure that people wear the proper gloves, eye protection that's needed, weight belts, things of that nature... And the city itself they issue, give out classes on how to lift stuff... We try to do a lot of in-house through our learning center and public services has education classes that we go to.		Previously trained electrician
Training (Existing Employee)	We also have additional training for specialized areas, like the zambonies have to go through a certain, it's an in-house course, in order to be zambonie trained to drive with everything from the maintenance to actual cutting the ice to replacing blades and stuff. Then they are also trained in the chillers so that they know also where that equipment is for safety in case of an emergency. So people can walk through that area but are far as putting their hands on the machinery and stuff like that you got to be trained and certified. Right now we've only got about 3 that are able to do that.	Location of dangerous pieces of equipment.	
Software	Compressor softw are - but mostly hardcopy usage		
Safety Info in Work Order	No		
Safety Info Storage	MSDS in a book held in the office		

Falls	Joe, Dan, & Tim	Safety Codes
	[VALVE AT ELEVATION] ...there's some valves up high. In the chiller room ...There's valves on there that you have to get up to	ATTRIBUTE: Working Height
	[MANLIFT PROTOCOLS] We do have a man lift and Brian's gone over operations with a few guys but he mainly uses it... We got a belt you put on and tie off to the bucket... And we also got safety rails and stuff like that, that lift up and down and lock you in.	PROTOCOL: Lift System ATTRIBUTE: Working Height PROTOCOL: Fall Arrest System

Hazardous Environment - Electrical	Joe, Dan, & Tim	Safety Codes
	[PPE & PROTOCOL – HOT WORK] We try not to work stuff hot, but occasionally they'll be situations where you have too. Safety glasses and trying to eliminate the amount of people that are around when there is going to be live, exposed electrical dangers... Also note that his boots are different than other folk's boots. Ricky and I wear steel toe boots but you have a composite boot.	PROTOCOL: Avoid hot work. PROTOCOL: Proper PPE
	[ARC FLASH] Anytime you are dealing with removing a wire or dealing with live, exposed electricity you present an arc flash potential. There's guards inside of the disconnects, inside of the main breakers in there, are flash guards.	PROTOCOL: Arc Flash Potential
	[Hot Stick Usage] A lot of people do. I call them death wands, sometimes they work, sometimes they don't. They are a good quick test but the only way to be sure is with a meter.	PROTOCOL: Hotsticks
	[ELECTRICAL PROTOCOL] people will just go off of somebody else's belief or assumption, that's off, there's no power there and I go to working on it and got shocked. You can't go off of somebody's telling you that something's turned off. You should always test it.	PROTOCOL: LO / TO PROTOCOL: Hotsicks
	[SECONDARY POWER SOURCE]...The only way the emergency backup is going to come on is say if a generator comes on and if you kill the power coming to it primarily and you have the transfer switch locked out or the generator itself locked out there's no way that, but you have to be cognizant and shut off both... And so you wouldn't necessarily know that there was emergency power unless you looked it up and see that it's a dual feed.	ATTRIBUTE: Disconnect Locations - Secondary Power Source

Hazardous Environment - Confined Space/Toxic Environment	Joe, Dan, & Tim	Safety Codes
	[TOXIC ENV. - GAS MASK FOR AMMONIA] So, example, they know that the gas mask is always going to be located right there at the desk. Now, it's up to the individual that's working and the person that's maybe helping him to take the gas mask with them when they start doing this just in case there is a leak. But then also to put it back when they leave because that's where it's supposed to stay. When you're taking it off, separating it from the ammonia, you're gonna get that ammonia leak, you need the mask on then because some guys are more or less trained in refrigeration, a lot of them don't wear the mask but you need the mask so that ammonia doesn't get in your lungs and stuff. So, when we go to separate the oil from the ammonia we highly suggest you wear the safety equipment. You'll want to put it on when that ammonia starts getting to you.	PROTOCOL: PPE ATTRIBUTE: Chemical Environment - Ammonia
	[CONFINED SPACE PROTOCOL] I guess, you gotta make sure everything is cut off so nothing starts up while you're in there. That's one of the safety rules. Make sure everything is shut down... Usually we'll identify the, identify the safety issues. I've been OSHA 10 and OSHA 30 certified so the first level, like you said, would stop at me and then if it had to go any further than that we have brought in outside contractors.	PROTOCOL: Confined Space - Procedure
	[HEARING PROTECTION - COMPRESSOR] I say it's the equivalent of a jackhammer... You should certainly wear ear protection if those compressors are running... Especially if you have multiple compressors.	ATTRIBUTE: Decibel Level PROTOCOL: Hearing Protection
	[TOXIC ENV. - CHLORINE GAS] I was in parks and recreation over swimming pools and this one we had gas chlorine, and you got a gas chlorine closet. You're supposed to hit the ventilation fan and then open the door, then spray it down (to knock the gas down to floor level), and then put on a gas mask... And I had one lifeguard that just sort of opened the door and walked in. He passed out right there.. Had not somebody else been there beside him when he opened that door and that chlorine sort of hit him, he'd a been a goner.	PROTOCOL: Toxic Environment - Protocol - Chlorine Gas

Contact With / Struck By	Joe, Dan, & Tim	Safety Codes
	[AUTOMATED EQUIP – DRIVE SHAFT0 Right off the bat you never know when the compressors gonna kick on so if you have any lose clothing near there, that does have a spinning drive shaft... They have partial guards on them but yes there still exposed, you can get caught up in them. And it's between where the impellers in there are the motors.	ATTRIBUTE: Automated Equipment PROTOCOL: Lockout/Tagout PROTOCOL: Proper Attire
	[AUTOMATED EQUIP – PRESSURIZED LINE] Well, I mean, the pumps that run the brine through the system they'll kick on. If you're in the middle of all that trying to change a valve or whatever... shut the pumps off. You can do that from the computer.	PROTOCOL: Valve Shutoff
	[AUOMATED EQUIP] Now we do have automated motors on, in the other room I showed you, where the coolers for the HVAC's are and they'll come on automatically.	ATTRIBUTE: Automated Equipment PROTOCOL: Lockout/Tagout
	[OVERHEAD EQUIP] The scoreboard when we laid it down, that's a big hazard... You have a lot of issues with scoreboards having coming out of the ceilings. In arenas.. And it's always happening in the movements. I haven't seen any that it happened where it's been stored up top or just hanging free or whatever it's always been that somebody's moving it while people are underneath it.. It's got a safety horn on it, anytime you move it goes off.	ATTRIBUTE: Overhead Equipment
	[OVERHEAD EQUIP] Curtain moves. They didn't put the curtain, okay you have a main curtain and two side curtains up there. If I had to guess it's probably, the main curtain's about 6,000 pounds... And it's a matter of bringing it down, putting it on forklifts. The guy then takes the chains and moves it forward. Then you start to bring it and swing it...You gotta take it, swing it and swing it forward as far as you can, go bring it back like like Tarzan (not mechanized)... what's worse is when it's on the side. Cause now they have to use 10 people on the curtain down manually as far as they can get it, let it down, then jump the chains and then when it starts to bring it up then you gotta hold it as he brings it up so it doesn't take off swinging dragging somebody behind it.	ATTRIBUTE: Overhead Equipment
	[PRESSURIZED LINE] ...they were digging, putting in that water treatment thing. Either somebody didn't mark it right or the guy that was doing the digging or whatever, didn't follow his protocols or whatever but when he cut that line out, I mean, that water about killed him.	ATTRIBUTE: Pressurized Line

	Joe, Dan, & Tim	Safety Codes
Dual Processes	[BUDDY SYSTEM – HAZARDOUS ENV] Well, first I ask that they have a buddy system, nobody goes in there to work on something without somebody there to help them out if we have those type hazards. Sometimes in the chillers though, example if they're gonna bleed off the oil or whatever, that should be a one man job so that he can shut the door which automatically locks that will keep anybody else from coming in unless they have a key.	PROTOCOL: Situational Buddy System

	Joe, Dan, & Tim	Safety Codes
Outside Factors to Safety - Environment	[HEAT PRODUCING ASSET – BURN POTENTIAL] Then also you have the issue, you know they give off a lot of heat and you have that manifold that is up in the air and even though it's not closed, if you are working on lights or something you could lean up against it and burn yourself.	ATTRIBUTE: Heat Producing Asset

Appendix J: Safety Literature Data Collection and Analysis Spreadsheets

Safety Literature Matrix
Safety Schema Development

Hazard Type	Source	Hazard	Hazard Definition	Safety Input	Safety Protocol	Protocol Requiremets / Minimum Testing
Harmful Environments & Substanaces	University of Minnesota Facilities Management	Hazardous Atmosphere - Confined Space	An atmosphere presenting a threat of death, acute injury, illness or disablement due to the presence of flammable, explosive, toxic, oxygen deficiency or enrichment, or otherwise injurious substances	Manhole / Tank	Permit Required Before Entry	Obtain permit via organizational standards
				Environmental Air Quality	Atmospheric Testing	Flammable gas or vapor concentrations greater than 10 percent of its lower explosive limit (>10% LEL).
				Oxygen Deficient / Carbon Monoxide Environment		Combustible particulate concentrations greater than 10 percent of the minimum explosive concentration of the particulate (>10% MEC)
						Atmospheric oxygen concentration either below 19.5 percent or above 23.5 percent
				Hazardous Chemicals		Toxic, corrosive or asphyxiate substance concentrations above Permissible Exposure Levels and/or Threshold Limit Values (> PEL and/or TLV).
						Any substance that is present at concentrations greater that the value established as Immediately Dangerous to Life and Health (> IDLH).
Harmful Environments & Substanaces	Duke University Facilities Management	Hearing Loss	Workers exposed to 85 dBA or above time-weighted average for an 8 hour period or 82 dBA for a 12 hour time-weighted average, measured on the A-scale, slow response, or equivalently, a dose of 50%	Environmental Decibel Level	Noise Dosimeter	An instrument that integrates a function of sound pressure over a period in such a manner that it directly indicates a noise dose
					Sound Level Meter	An instrument for the measurement of sound level
Falls	Creighton Facilitity Management	Fall	Employees working near unprotected edges or holes, including skylights, which are six feet above a lower level, will be protected from falling by the use of guard rails, positioning devices, a warning line system, safety monitoring system or personal fall arrest system.	Working Height	Fall Arrest System	Fall arrest systems will consist of a harness, self-retracting lanyard with a deceleration device and anchor point. Short rope lanyards may be utilized in the buckets of man lifts.
					Ladder Safety	Choose the right ladder style (i.e., step or extension), size and duty rating for the job. Use fiberglass ladders if there is even a remote possibility of working near electricity.
Harmful Environments & Substanaces	Creighton Facilitity Management	Asbestos	Airborne carcinogen present in materials	Asbestos Poetential	Asbestos Management	Facilities Management employees are prohibited from performing any work that will intentionally disturb asbestos containing materials.
				Environmental Air Quality	Breathing Apparatus	Facilities Management employees are prohibited from performing work in any areas that will, or may, expose them to airborne asbestos where abatement is in progress.
						Facilities Management employees are permitted to work in areas where asbestos containing materials exist as long as the materials are safe from becoming airborne and providing the employee has the proper PPE and training.
Harmful Environments & Substanaces AND Contact With / Struck By	Creighton Facilitity Management	Hazardous Energy	All energy sources that might cause unexpected movement, personal injury or property damage. This includes electrical, mechanical, hydraulic, thermal, pneumatic, compressed gas energy, potential energy from suspended or overhead objects and compressed springs.	Automated Equipment	Lockout / Tagout	A tagout system will always be used in addition to the lockout system. Tagout devices must indicate the reason for the lockout; how that person may be reached; the identity of the person who applied the device; and the date and time the tag was placed.
				Hazardous Energy	Permits	De-Engergize and Re-energize Protocols
				Electrical Disconnect Locations	Lockout / Tagout	Same as above
Falls	Office of Compliance	Fall	Falls from heights involving scaffolding, rooftops and ledges	Roof / Deck	Fall Arrest System	Wear a full body harness when required or when working from elevations such as rooftops or elevated platforms greater than four feet.
				Ledge / Hole	Barricading	If working in a high traffic area, isolate the work area to prevent potential falling objects from striking people below.

Harmful Environments & Substances	Government of Alberta Canada	Environment Temperature	Employees working in hot and cold outdoor environments	Outdoor Environment	Weather Considerations	Serious health issues can happen when you are exposed to extremes of heat or cold. Working in heat can affect the body with: Mental Changes – increased irritation, mood changes, depression, aggression, and anger. Physical Responses – increased heart rate, increased sweating, muscle cramps, changes in breathing patterns, dizziness, faintness, or "prickly heat" (heat rash). Working in cold can affect the body with: Mental Changes – loss of alertness, slurred speech, fatigue, lethargy or apathy. Physical Responses – general discomfort (feeling cold), and a loss of sensitivity and dexterity in fingers, hands and toes. At lower temperatures, deep muscles can be affected, reducing muscle strength and flexibility.
Contact With / Struck By	USDL	Equipment Motion	About one-half of all workplace amputations occur in the manufacturing sector and the rest occur across the construction, agriculture, wholesale and retail trade, and service industries. These injuries result from using stationary machines such as saws, presses, conveyors, and bending, rolling, or shaping machines as well as from powered and non-powered hand tools, forklifts, doors, and trash compactors; and during materials handling activities.	Automated Equipment Manual Equipment Hazardous Energy	Lockout / Tagout	Anyone working around stationary equipment should be able to identify potential amputation hazards. Understanding the mechanical components of machinery, the mechanical motion that occurs at or near these components, and specific worker activities performed in conjunction with machinery operation will help workers avoid injury.

Harmful Environments & Substances	EPA	Lead Paint	Building or assets built prior to 1978 may have lead based paint	Lead Paint Potential	Breathing Apparatus	It's not just lead paint chips that poison. Contamination can be caused by only a little bit of lead dust that is easily absorbed by anyone who inhales or ingests it.
					Lead Management	Federal law requires that if you or someone on your staff is performing the work your firm must be Lead-Safe Certified and your staff trained in lead-safe work practices
Harmful Environments & Substances	USDL	Hazardous Energy	The standard covers the servicing and maintenance of machines and equipment in which the unexpected energization or start up of the macines or equipment, or release of stored energy, could harm employees.	Hazardous Energy	Lockout / Tagout	Energy control program. The employer shall establish a program consisting of energy control procedures, employee training and periodic inspections to ensure that before any employee performs any servicing or maintenance on a machine or equipment where the unexpected energizing, startup or release of stored
Falls	Department of the Navy	Fall	This Guide establishes criteria and requirements for developing and managing Fall Protection programs to protect all Navy personnel (military and Department of Navy civilians) at Navy Ashore Activities.	Roof / Deck	Fall Arrest System	At construction sites, workers (contractors only) shall adhere to the threshold height no greater than 6 feet, as per US Army Corps of Engineers (USACE), Safety and Health Requirements Manual EM 385-1-1, and 29 CFR 1926.500, Subpart 'M', Fall Protection in Construction Industry.
Harmful Environments & Substances	Coastal Carolina University	Hazardous Atmosphere - Exhaust Producing	Gasoline engines within a closed quarters	Exhaust Producing Asset	Ventilation	Must not run a gasoline engine in closed quarters without proper ventilation

Appendix K: Data Validation Interview Questions

1. What is your current position?
    a. What type of activities do you execute on a daily basis?
    b. Do you manage any staff? If so, how many?

2. Appendix A.1 holds the list of safety inputs and protocols related to mitigating Falls
    a. In terms of working at elevation, do you see any safety inputs that you may have in addition to the items listed? A safety input is an item that a FM worker would be required to know prior to working at elevation. *Be sure to define each input and protocol as it relates to the research.*
    b. In regards to safety protocols, do you believe the list of mitigation techniques is comprehensive, related to each input?
    c. Are any of the inputs or protocols unimportant? In other words, the input or protocol does not affect the FM worker while working at elevation?

3. Appendix A.2 holds the list of safety inputs and protocols related to mitigating Contact
    a. In terms of working near mechanisms that could come into contact with a worker, do you see any safety inputs that you may have in addition to the items listed?
    b. In regards to safety protocols, do you believe the list of mitigation techniques is comprehensive, related to each input?
    c. Are any of the inputs or protocols unimportant? In other words, the input or protocol does not affect the FM worker while working at elevation?

4. Appendix A.3 holds the list of safety inputs and protocols related to mitigating Harmful Environments and Substances.
    a. In terms of working in environments that are potentially dangerous to FM workers, do you see any safety inputs that you may have in addition to the items listed? Keep in mind that harmful environments and substances category incorporates air quality, oxygen deficiency, chemicals, electrical hazards, heat, and noise.
    b. In regards to safety protocols, do you believe the list of mitigation techniques is comprehensive, related to each input?
    c. Are any of the inputs or protocols unimportant? In other words, the input or protocol does not affect the FM worker while working at elevation?

5. Appendix B - Mind Mapping
    a. As noted in the introduction, the safety inputs we have discussed were placed into a categorical format using a research technique known as mind mapping. At this point we will look through those mind maps and validate the categorical hierarchy and discuss where any new inputs discussed in this meeting should be placed.

6. Is there anything you wish you were asked in this interview that was not mentioned or wish to share?

Appendix L: Data Validation Interview Data Adjustments/Additions

This section presents the complete list of Safety Inputs, Data Sourcing, and Protocols. The items list in black were identified during the Define Phase through Data Collection Interviews, Safety Literature, and FACE reports. The items listed in read were additions or adjustments made to the original list during the Measure Phase using the Data Validation Interviews.

HARMFUL ENVIRONMENTS & SUBSTANCES				
		DATA SOURCING		
Safety Input	Typical Production Phase	Primary Developer	Method of Transfer	*Knowledge* : Relates to Safety Protocol
Hazardous Energy	Design	Arch / Engineer	Native BIM Model	Lockout/Tagout
				Hot Sticks/Metering
				Permits
				Arc Flash Protection
Elec. Disconnect Location(s)	Design	Arch / Engineer	Native BIM Model	Lockout/Tagout
Voltage	Design	Arch / Engineer	Native BIM Model	Lockout/Tagout
				Arc Flash Protection
				Permits
				Hot Sticks/Metering
Approx. Disconnect Distance	Design	Arch / Engineer	Native BIM Model	Lockout/Tagout
Asbestos Potential	FM	FM Staff	FM Safety Related Information	Asbestos Management
				Respiratory Protection
Environment Decibel Level	Construction	Manufacturer / Subcontractor	Non-3D	Hearing Protection / Noise Dampening
				Noise Monitoring
Environmental Air Quality	Design	Arch / Engineer	Native BIM Model	SDS / Chemical Management
				Respiratory Protection
				Refrigerant Management
				PCB Management
				Silica Management
				Asbestos Management
				Lead Management
				Permits
Manhole or Tank	Design	Arch / Engineer	Native BIM Model	Hearing Protection / Noise Dampening
				Noise Monitoring
				SDS / Chemical Management
				Air Monitoring
				Temperature Monitoring
				Valve Location(s)
				Confined Space Protocol
				Permits
				Ventilation
Oxygen Deficient / Oxygen Enriched / Carbon Monoxide Environment	Design	Arch / Engineer	Native BIM Model	Permits
				Air Monitoring
				Ventilation
				Respiratory Protection
Particulate Environment	Design	Arch / Engineer	Native BIM Model	Air Monitoring
				Ventilation
				Respiratory Protection
Exhaust Producing Asset	FM	FM Staff	FM Safety Related Information	Ventilation

Flooding Potential	Design	Arch / Engineer	Native BIM Model	Inflatable Valve
				Valve Location
				Safety Line
Hazardous Asset Temperature	Design	Arch / Engineer	Native BIM Model	Burn Mitigation / Frostbite Mitigation / Hypo (Hyper)thermia
Outdoor Environment	Design	Arch / Engineer	Native BIM Model	Weather Considerations - Heat, Cold, Precipitation, Wind
				Nature - Animals, Allergens, Plant Life
Lead Potential	FM	FM Staff	FM Safety Related Information	Lead Management
				Respiratory Protection
Hazardous Chemical Production / Storage	Design	Arch / Engineer	Native BIM Model	SDS / Chemical Management
				Air Monitoring
				Secondary Containment
				Ventilation
				Respiratory Protection
				Valve Location
Radiation	Design	Arch / Engineer	Native BIM Model	Monitoring
				Radiation Management
Polychlorinated Biphenyls (PCB) Potential	FM	FM Staff	FM Safety Related Information	PCB Management
				Respiratory Protection

168

FALLS

Safety Input	DATA SOURCING			*Knowledge* : Relates to Safety Protocol
	Typical Production Phase	Primary Developer	Method of Transfer	
Maintenance Requires Lift System	All	All	Native BIM Model, Non-3D, or FM Safety Related Information	Lift System with Condition Assessment
				Working Height
				Fall Arrest System / Anchorage
Roof / Deck	Design	Arch / Engineer	Native BIM Model	Lift System
				Chemical Venting (Industrial Hygiene)
				Fall Arrest System / Anchorage
				Barricading / Notification
				Outdoor Environment
Ledge / Hole	Design	Arch / Engineer	Native BIM Model	Lift System
				Fall Arrest System / Anchorage
				Safety Line
				Barricading / Notification

CONTACT WITH / STRUCK BY

Safety Input	DATA SOURCING			*Knowledge* : Relates to Safety Protocol
	Typical Production Phase	Primary Developer	Method of Transfer	
Manual Crushing/Rotating/Slicing Mechanism	Construction	Manufacturer / Subcontractor	Native BIM Model or Non-3D	Lockout/Tagout
				Barricading / Notification
Automated Crushing/Rotating/Slicing Mechanism	Construction	Manufacturer / Subcontractor	Native BIM Model or Non-3D	Lockout/Tagout
				Hot Sticks/Metering
				Permits
				Barricading / Notification
Suction / Pressure Line	Design	Arch / Engineer	Native BIM Model	Safety Line
				Burn Mitigation / Frostbite Mitigation / Hypo (Hyper)thermia
				Valve Location(s)
				Barricading / Notification
Valve Location(s)	Design	Arch / Engineer	Native BIM Model	Line Isolation
Overhead Equipment	All	All	Native BIM Model, Non-3D, or FM Safety Related Information	Barricading / Notification
				Approach Vector
				Support Structure
				Equipment Weight
Approx. Valve Location Distances	Design	Arch / Engineer	Native BIM Model	Line Isolation
Asset Support Structure	Design	Arch / Engineer	Native BIM Model	Approach Vector

CHANGES

Remove Paint from Lead Potential
Change "Self-Contained Breathing" to "Respitory Protection"
Add "Radiation" to Harmful Environment Inputs – Milliservients of radiation determine danger, Geiger Counter measures (20 mSV per year is a typical nuclear power plant worers exposure)
Add Oxygen Enriched
Add Cold Producing Asset & Frostbite Mitigation / Hyppothermia
Add silica danger
Temperature in Manhole
Add Nature Considerations to Outdoor Environment
Add Industrial Hygene or Chemical Venting at Roof
Address harmful temperature in suction or pressure lines
Support stucture for equipment
PCB Concerns Added
Secondary Containment added as a mitigation technique
Added Approach Vectors

FOR EACH INPUT

Verify Surroundings
Verify PPE Conditions
Qualified Personnel

Appendix M: Safety Input Relational Information as Formulated in the ASIT

The following table presents the relationships formulated within the ASIT. A "Yes" response to any Primary Input requires values for the associated Dependent Inputs.

Primary Input	Dependent Input Requiring Value
Manual Crushing / Rotating / Slicing Mechanism	Disconnect Mechanism Location (Manual Only)
	Harmful Force (Y/N)
Automated Crushing / Rotating / Slicing Mechanism	Limit Switch Location (Where In Equipment)
	Harmful Force (Y/N)
	Disconnect Location (Panel Number)
	Secondary Feed Location (Panel Number or None)
	Approximate Disconnect Distance (in feet)
Suction / Pressure Line	Harmful Force (Y/N)
	Valve Location (Valve Number)
	Secondary Valve Location (Valve Number or None)
	Line Size (in inches)
	Approximate Valve Location Distance (in feet)
	Harmful Temperature (Y/N)
Overhead Equipment	Maintenance Working Height (in feet)
	Weight (in pounds)
	Support Structure Type (Platform, Threaded Rod, Etc.)
Environmental Air Quality Hazards Present	Lead Present (Yes/No)
	Oxygen Deficient or Enriched / Carbon Monoxide Environment (Yes/No)
	Chemical No.1 Present
	Chemical No. 2 Present (List Chemical or None)
	Chemical No. 3 Present (List Chemical or None)
	Particulate Present (Yes/No)
	Asbestos Present (Yes/No)
	PCBs Present (YES/NO)
Environmental Decibel Level Hazard	Environmental Decibel Level (in dBA)
Hazardous Energy / Live Current Present	Disconnect Location (Panel Number)
	Secondary Feed Location (Panel Number or None)
	Approximate Disconnect Distance (in feet)
	Voltage (in volts)
Manhole /Tank / Confined Space	Valve Location (Valve Number)
	Secondary Valve Location (Valve Number or None)
	Approximate Valve Location Distance (in feet)
	Harmful Temperature (Y/N)
	Flooding Potential Exists (Y/N)

	Chemical Storage (Type or None)
Hazardous Chemical Production Transmission	Chemical No.1 Present
	Chemical No. 2 Present (List Chemical or None)
	Chemical No. 3 Present (List Chemical or None)
Radiation	Milliservients of Radiation
Heat / Cold Producing Asset	Harmful Temperature (Y/N)
Maintenance Requires Lift System	Maintenance Working Height (in feet)

In a single instance, a "Yes" response to a Primary Input automates a "Yes" response to another Primary Input. If an asset has an "Automated Crushing/Rotating/Slicing Mechanism" this system will require a "Yes" to "Hazardous Energy."

Primary Input	Primary Input Requiring Value
Automated Crushing/Rotating/Slicing Mechanism	Hazardous Energy

In most cases Independent Inputs do not have Dependent Inputs and therefore are categorized separately, however, the below presets the single example of two Independent Inputs logically related. This example is also presented in *Section 5.1 Phase I - Data Loading.*

Independent Input	Independent Input Requiring Value
Located on Roof / Deck	Outdoor Environment (Auto YES)

In a single instance, a "Yes" response to a Dependent Input prompts the system to require a value for another Dependent Input. The Primary Input "Manhole / Tank / Confined Space" has a Dependent Input "Chemical Storage (Yes or None)." If a response of "YES" is given to this value, the system will prompt the user to input the chemicals present.

Dependent Input	Dependent Input Requiring Value
Chemical Storage (Yes or None)	Chemical No.1 Present
	Chemical No. 2 Present (List Chemical or None)
	Chemical No. 3 Present (List Chemical or None)