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Lifecycle Cost Evaluation of Flexible Facility Designs

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LIFECYCLE COST EVALUATION OF FLEXIBLE FACILITY DESIGNS

THESIS

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Abstract

The purpose of this research is to ascertain the type of facility design, standard, robust, or flexible, that yields the greatest lower lifecycle costs (LCC) savings to the USAF. To this aim, the researcher constructed a Monte Carlo simulation to determine the LCC for flexible, robust, and standard administrative facility designs for thousands of potential facility lifecycles. The simulation also illustrates the circumstances under which each type of design would result in the lowest LCC. The results of this research will show the USAF the importance of focusing on LCC and designing flexible facilities. Standard and robust designs are the staples of the current practice. This research found implementing flexible facility design into practice is advantageous to the United States Air Force (USAF) for two key reasons: (1) Flexible designs allows USAF facilities to easily adapt to changes in user demands and, (2) when compared to both standard and robust designs, flexible designs have LCC.

Acknowledgments

I would like to thank my wife. Without her encouragement, support, and love this research would not have been possible. Her tolerance of my constant discussion of my research is a testament in itself of her amazing devotion and love. I would also like to thank my kids for their patience and faith in me. All of you were a huge motivation to achieving this research.

Trevor P. Ellis

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I. Introduction

Background

In the United States Air Force (USAF) Strategic Master Plan (SMP) (2015) and "America's Air Force: A Call to the Future" (2014), the Secretary of the Air Force and Chief of Staff of the Air Force lay out a strategy focused on addressing uncertainty and change throughout the next 30-years. A major objective of the strategic master plan is for the Air Force to find a means to address uncertainty and change with fewer resources (United States Air Force, 2015). The Secretary and Chief of Staff have issued a call for the development of assets that have the ability to adapt and respond to changes (The United States Air Force, 2014). In order to answer this call, Air Force must design assets for the uncertainty of future demands.

Uncertainty and Facilities

Air Force facilities experience a great deal of uncertainty due to numerous changes in demands across their 40-plus-year lifecycles (Uddin, Hudson, & Haas, 2013). This demand uncertainty is a problem because the typical facility is not designed to accommodate future demand changes (Abrol, 2014). Air Force civil engineers are only required to consider future requirements three to five years from the initial planning process (United State Air Force Civil Engineering, 2014). This initial planning process does not take into account future, unknown demands. When a new demand does occur, the facility requires an expensive and time intensive modification. This thesis explores the idea of reduced expenses, effort, and time to modify facilities through facility designs that consider uncertainty in the demands of an Air Force facility

In order to plan for uncertainty in Air Force facility demand, it is important to fully understand the true cost of facilities. At present, the Air Force funds new facility construction projects based on the initial construction cost. However, cost estimates for 120 Air Force random sample administrative facilities, Appendix A, demonstrate that the initial construction costs on average only consist of 34 percent of the overall facility 40-year lifecycle costs (LCC), see Figure 1. The LCC estimates were generated using PACES and CostLab estimation software. LCC are a much better representation of the true cost of a facility as it includes initial construction, maintenance and repair (M&R), operating, and modification costs (Ryan, Jacques, & Colombi, 2011). Because facilities have decades long life spans, a small decrease to annual M&R, operating, or modification cost can reduce the overall LCC of a facility significantly (de Neufville & Scholtes, 2011).

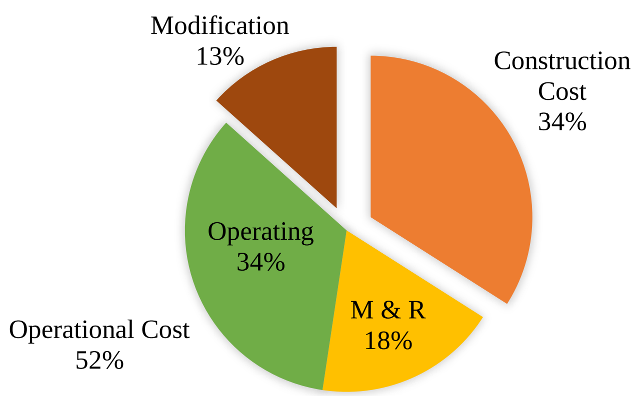


Figure 1: 40 Year Facility LCC Breakdown Averages

Robustness and flexibility are two techniques for creating designs that can adequately address uncertainty, at reduced LCC, time, and effort (Hastings & McManus, 2004; Brown & Eremenko, 2008). *Robustness* refers to the ability of a system, in response to a change, to maintain its current level of service (de Weck, Ross, & Rhodes, 2012). Currently, the practice of facility design in the Air Force addresses uncertainty through "over-design". Over-designing a facility utilizes the concept of robustness and creates a robust design. The practice of robust design involves front-loading requirements in the initial design in order to meet future facility demands. For example, consider a requirement to build a new facility that must support fifty personnel now and an potential for additional fifty personnel five years later. A robust design approach is to build a new facility now to support 100 personnel. The robust design reduces the overall time and cost by combining the future requirement into the initial facility construction. This type of design may significantly reduce or eliminate future modification costs.

Flexibility is the second technique for creating designs that address uncertainty. *Flexibility* is the ability of a constructed facility to be easily modified in response to a change in requirements (Ryan, Jacques, & Colombi, 2012). A flexible design uses the concept of flexibility to create a facility that can be easily modified. Flexible facilities are smaller than robust facilities and as a result, are faster and less expensive to modify (de Neufville & Scholtes, 2011, p. 39). Flexible design focuses on meeting the current requirements with the capability to adapt to a range of potential future demands. By designing a facility for a range of demands, it is possible to reduce LCC. Using the same example as before in which a requirement exists to build a new facility for fifty personnel now, with a potential future requirement of an additional fifty personnel, a flexible design approach would involve designing a facility for fifty personnel now but provides the capability to grow or to be more easily modified later to support fifty additional personnel. Growth capabilities might include adding an additional story to the facility later in the lifecycle or enlarging the facility foundation and other support systems to reduce the costs of future demand increases.

Research Objective/Problem Statement

The Secretary and Chief of Staff of the Air Force have called for systems that respond easily, and with reduced cost, to uncertainty and change (The United States Air Force, 2014). To meet that directive, the facility design process needs to produce flexible designs that have the ability to adapt to changes in demand. Due to the number of facilities and the costs associated with them, it is critical that the Air Force facility design process evaluate and implement flexible design alternatives. However, to create flexible facilities, the current design process must change to incorporate funding based on LCC, predicting ranges of demands, and designing for variation (de Neufville & Scholtes, 2011). The research objective is to demonstrate that the process changes required for creating flexible design will enable Air Force facilities to meet changing demands more efficiently and with reduced LCC.

Investigative Questions

The majority of facilities in the Air Force are standard or robust designs. Yet, research shows that flexible designs may substantially reduce LCC in high uncertainty situations (de Neufville & Scholtes, 2011). With the reduction to Air Froce budget combined with changing mission requirements and reduction in manpower, the Air Force must make smart investments when creating new facilities. Flexible designs may provide the Air Force with the ability to be easily modified to address demand changes while achieving reduced cost. Research into the LCC of flexible designs remains limited and not all Air Force facilities will undergo modifications throughout their life-cycle. Since implementing flexible designs over robust and standard designs requires changes to the design process, the benefits of flexible designs need to be studied in order for the Air Force understand when flexible designs should be used. For this reason, this thesis will answer the following two research questions:

- When comparing flexible, robust, and standard designs for an administrative facility, which alternative represents the greatest LCC savings to the Air Force?
- Under what facility characteristics do flexible, robust, and standard designs result in the lowest LCC?

Overview

The organization of the remainder of this thesis document is as follows: literature review, methodology, analysis and results, and conclusions and recommendations. Chapter 2 will contain the literature review, and will include definitions of key terms, the current state of flexible design research, and tools and techniques for evaluating flexible alternatives. Chapter 3 will describe the proposed method to answer the research and investigative questions. Chapter 4 will discuss the analysis and results and contains the results of logistic regression, distribution goodness of fit tests, and Monte Carlo simulation. Chapter 5 addresses interpretations, conclusions, and recommendations of the results and proposes future research areas.

Limitations

This research evaluates two techniques to address uncertainty: flexibility and robustness. However, a third method that addresses uncertainty is adaptability. Adaptability is the ability of a system, after it has been fielded, to easily modify itself to meet a change (Ryan, Jacques, & Colombi, 2012, p. 108). Adaptability is different from flexibility in that adaptability is the ability of a system to easily modify itself, where flexibility is the ability of a system to be easily modified in response to a change. Adaptability is valuable in a system and may be better than flexibility or robustness in some cases. An example of an adaptable design is a heating, ventilation, and air conditioning (HVAC) controller in a facility. In the event of a change in room temperature the HVAC system will automatically turn on to return the room back to preprogramed parameters. Adaptable design plays a large role in software systems (Ross A. M., 2006) but remains limited in facilities and requires an increased level of detail and effort. In addition, designing a facility to react automatically to the majority of potential demands would be extremely difficult, if not impossible, and would require a large amount of resources. For these reasons, this research removed an adaptable design from consideration.

Another limitation is the ability to assign a value to design alternatives. This research focuses on LCC. However, several different factors contribute to the value of flexibility and robustness such as time, effort, cost, and performance. The task of measuring the value of designs is its own research topic due to its scope. For this research, facility LCC determines the value of a design alternative.

II. Literature Review

Chapter Overview

This research presents a literature review on the concept of flexibility in engineering design and methods used to measure design alternatives. The first section discusses definitions to key terms and explores the relationships between flexibility, robustness, and adaptability. The second section addresses the significance of flexibility and robustness. The third section addresses current methods to evaluate design alternatives throughout a facility's lifecycle. The fourth section discusses facility cost estimating systems and their benefits. The conclusion to this literature review provides an analysis of the key methods of the preceding sections.

Terminology

Key Terms

Table 1 contains a summary of key terms and their definitions. Further discussion of each term follow the order of terms listed in

Table 1.

Table 1: Terminologies and Definitions

Term	Definition
Uncertainty	"The inability to predict the future with precision" (Hazelrigg, 2012, p. 16).
Functional Requirements	Requirements that the facility must meet to address the initial need (Glinz, 2007; ESD Symposium Committee, 2001).
Non-Functional or "ilities"	Are desired properties of a facility and determine facility value after construction (de Weck, Ross, & Rhodes, 2012).
Changeability	The ability of a system to manage internal and external changes (Schulz, Fricke, & Igenbergs, 2000).
Internal Change	Are changes that are within the system boundary (Ross, Rhodes, & Hastings, 2008).
External Change	Are changes that are outside the system boundary (Ross, Rhodes, & Hastings, 2008).
Robustness	The ability of a system, in response to a change, to maintain its current level of service (de Weck, Ross, & Rhodes, 2012).
Flexibility	The ability of a system, after it has been fielded, to adapt easily to an external change in requirements (Ryan, Jacques, & Colombi, 2012).
Adaptability	The ability of a system, after it has been fielded, to easily modify itself to a change in requirements (Ryan, Jacques, & Colombi, 2012).

Uncertainty

One of the requirements of Air Force Strategic Master Plan (2015) is to create facility designs that can adapt uncertain demands (United States Air Force, 2015). Where the definition of uncertainty is "the inability to predict the future with precision" (Hazelrigg, 2012, p. 16). One way to capture the uncertainty of facility demands is to use ranges instead of point estimates (de Neufville & Scholtes, 2011). For example, users can represent a future facility demand as a 50 to 150 personnel increase between years one and three, rather than a 100 personnel increase at year two. Using ranges will provide designers the opportunity to create more accurate facility design requirements.

Functional Requirements

Requirements are what drive the design of a facility, and there are two main types: functional and non-functional. Functional requirements are requirements the facility must meet to address the initial need (Glinz, 2007; ESD Symposium Committee, 2001). Examples of functional requirements for a facility are providing work area for employees (i.e., shelter), providing a climate-controlled space, etc. Functional requirements contribute to how well the new facility meets the initial needs.

On the other hand, non-functional requirements contribute to the facility's performance across the facility lifecycle (Crawley, et al., 2004). Non-functional requirements can affect LCC components of M&R, energy, and future modification costs. Reliability, resiliency, and maintainability are several examples of non-functional requirements. Although non-functional requirements do not directly address the initial facility needs, they dictate the quality to which functional needs are delivered. Non-functional requirements can reduce LCC through robustness and flexibility requirements. While the current literature mostly agrees on the definition of functional requirements (Glinz, 2007), the literature does not agree on the definition of non-functional requirements (Ryan, Jacques, & Colombi, 2011; Beesemyer, Ross, & Rhodes, 2012; Glinz, 2007).

Functional requirements provide value initially, while non-functional requirements add value throughout the life-cycle (Crawley, et al., 2004). The opportunity to increase a facility's lifecycle value through non-functional requirements is certainly worth investigating. Non-functional requirements are often referred to as "-ilities." Changeability, flexibility, robustness, and adaptability are some further examples. Unfortunately, the literature does not agree on definitions for many of the individual "-ilities" (Beesemyer, Ross, & Rhodes, 2012; de Neufville & Scholtes, 2011; de Weck, Ross, & Rhodes, 2012; Ryan, Jacques, & Colombi, 2011; Ryan, Jacques, & Colombi, 2012). Despite the lack of agreement on the definitions, there is agreement that non-functional requirements are important and designers should build them into their designs (Glinz, 2007). The lack of agreement on definitions makes clearly stating each "-ility" definition, extremley important (Beesemyer, Ross, & Rhodes, 2012). Therefore, for this research, non-fuctional requirments are defined as desired properties of a facility that contribute to a facility's value after construction (de Weck, Ross, & Rhodes, 2012).

In addition to being poorly defined, non-functional requirements are also "hard to measure, verify and validate" (Beesemyer, Ross, & Rhodes, 2012; de Weck, Ross, & Rhodes, 2012). Consequently, the value individual non-functional requirements add to a facility remains difficult to determine. A large part of the problems associated with "ilities" is not only the lack of standard definition but also the lack of agreement on how "ilities" relate and function together (de Weck, Ross, & Rhodes, 2012).

Research by de Weck, Ross, and Rhodes (2012) shows evaluating sets of "-ilities" together may increase system value. The authors determined that a means to end hierarchy exists between different "-ilities." Unfortunately, the authors did not find a consistent agreed upon hierarchy or relationship between "-ilities" (de Weck, Ross, & Rhodes, 2012). As non-functional requirement research progresses, it is important not only to define individual "-ilities" but establish the relationship between them.

Ability to Change

Many different non-fuctional requirements exist and all of them add value to a system, but for the sake of this paper, the focus is on the non-functional requirements that add value in the face of uncertainty and change, where a change refers to a modification to a constructed facility (Wright, 1997). The emphasis of this literature review is on four change related non-functional requirements: changeability, flexibility, adaptability, and robustness. Change related non-functional requirements add value to a facility when a change occurs (de Weck, Ross, & Rhodes, 2012). Flexibility, adaptability, and robustness fall under changeability as shown in Figure 2 (Ryan, Jacques, & Colombi, 2012; Fricke & Schulz, 2005).

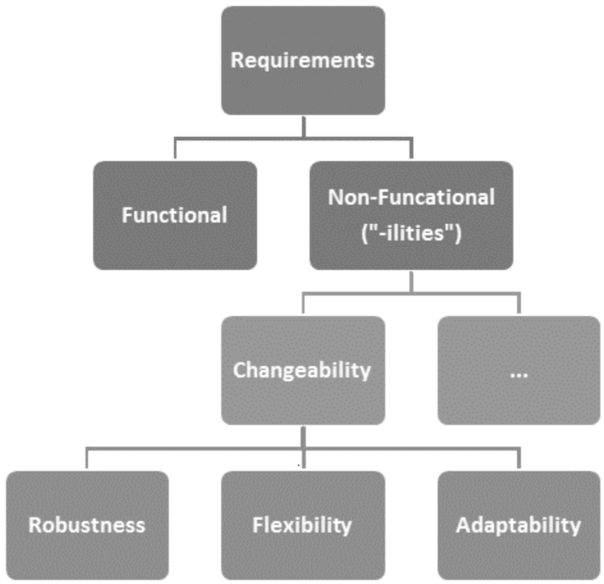


Figure 2: Hierarchy of "ilities"

Changeability is the ability of a system to manage internal and external changes (Schulz, Fricke, & Igenbergs, 2000). Internal changes are changes within the system boundary. An example of an internal change is an automatic HVAC software update. External changes are changes outside the system boundary such as building renovations (Ross, Rhodes, & Hastings, 2008). When a change occurs, a facility's changeability can either meet the change with its current capabilities, or the facility requires some modification. If the facility experiences an interial change and adapts to meet the change, then the facility's adaptability is the focus. If the facility experiences an exterior change and requires modification, then the facility's flexibility is the focus. Flexbility is the ability of a system, after it has been fielded, to adapt easily to an external change in requirements (Ryan, Jacques, & Colombi, 2012). If the facility's capabilities meet or exceeds a change, it is referred to as the facility's robustness. Robustness is the ability of a system, in response to a change, to maintain its current level of service (de Weck, Ross, & Rhodes, 2012).

Accounting for Robustness and Flexibility in Facility Designs.

Researcher have suggested that designing robustness and flexibility into a design is important in response to uncertainty (Hastings & McManus, 2004; Brown & Eremenko, 2008). Robustness and flexibility are, to some degree, a part of every facility design. To produce the greatest returns, Saari and Heikkila (2008) also suggest that initial design needs to incorporate flexibility and robustness. Designing robustness and flexibility in large amounts into a facility requires a prediction of the demands a facility may encounter (de Neufville & Scholtes, 2011); however, demand is hard to predict in facilities with 40-plus years of service life (Uddin, Hudson, & Haas, 2013; de Neufville & Scholtes, 2011), large-scope requirements, and the amount of demand uncertainty. Instead of designing a facility on one prediction of demand, de Neufville and Scholtes (2011) argue that designers should use a range of potential facility demands (de Neufville & Scholtes, 2011). When using a range of potential demands, robustness enables the facility to meet, without modifications, a majority of potential future demands. Likewise, given a range of potential demands, flexibility can enable the design of a facility that meets current requirements with the capability to adapt easily later to most of the potential demand change possibilities.

Limitations of Adaptable Design

Designing adaptability into a design provides opportunities to increase value by reducing LCC and improving facility performance (Ross A. M., 2006). Adaptability would provide a facility with the ability to easily modify itself to meet a change. Adaptability has proven to be extremely valuable in software systems (Ross A. M., 2006). For example, the ability of a facility HVAC system to change its parameter in response to an automatic software update has led to decrease facility maintenance hours. However, facilities contain only limited amount of software systems and adaptable infrastructure designs receive only limited research.

Design Alternative Valuation Studies

Flexible, robust, and standard designs all have the ability to increase a facility's performance and reduce LCC depending on the situation. Assigning a value to a design based on performance across a range of potential demands is critical to evaluating designs. Representing each designs alternative in terms of cost enables the evaluation and selection of the best design. Many different methods exist to valuate designs, and this section will describe several different options and discuss their benefits and limitations. The first half of this section describes two general methods for valuating a design across a lifecycle. The second half of this section introduces six improved methods to valuate designs.

General Methods

Many early studies such as Mayer & Kazakidis (2007) and Brown & Eremoenko (2008) use net present value (NPV) to assign a value to a design. NPV is a calculated value of an alternative, across a given period, expressed in present time (Eschenbach, 2011). The NPV is the cost that if initially invested at a set interest rate, could pay the LCC through year four. When valuating an alternative across a single lifecycle, NPV is a good method to use as it is easy to understand and implement (Eschenbach, 2011). However, NPV is impossible to calculate using ranges of potential costs. Therefore, NPV by itself is not a good option in situations with uncertainty (Ryan, Jacques, & Colombi, 2011; Dessureault, Kazakidis, & Mayer, 2007). Another approach is real options analysis (ROA), which was used by Mayer and Kazakidis, and is a process of valuating an asset using the option price (Dessureault, Kazakidis, & Mayer, 2007). ROA remains preferred over NPV, because it can manage large amounts of uncertainty (Ryan, Jacques, & Colombi, 2011). Two assumptions remove ROA as a possible tool to valuate facility design. First, there must be an option to do nothing, because an ROA value cannot be negative (Eschenbach, 2011). Second, the valuated asset requires an option price and therefore must be traded on a market (Ryan, Jacques, & Colombi, 2011; Dessureault, Kazakidis, & Mayer, 2007).

Improved Methods

This section describes three improved methods for evaluating flexible designs: Epoch Era Analysis (EEA), Value-Centric Design (VCD), and de Neufville and Scholtes' Monte Carlo Simulation (MCS) framework. In addition Current Expected Value Lifecycle Cost will be discussed as a potential inprovement to VCD and design catalogs will be discussed to improve the performance of de Neufville and Scholtes' MCS. Each one of the improved methods has the capability to capture uncertainty.

In 2006, Ross developed a method that determines when it is beneficial to design "-ility" attributes into a system. His approach is called Epoch Era Analysis (EEA) – where an epoch is a set period of time and era is set group of epochs. EEA starts by generating a range of potential future demands and a timeframe on when in the system life span a demand may occur. Then, epochs time intervals are chosen based on the timeframe of future demands. Next, changes in demand are represented in each epoch. Figure 3 shows an example of an era broken down into epochs. Lastly, each epoch in the sequence is evaluated on what "-ility" attributes result in the lowest cost (Ross, 2006). EEA is a method for simulating a range of system demands. EEA allows for separate demand prediction formulas for each epoch, which increases the accuracy of a simulation. EEA also excels a finding the lowest cost path of a design (Ross, 2006). However, to evaluate costs at each epoch requires an intense understanding and description of the modifications performed.

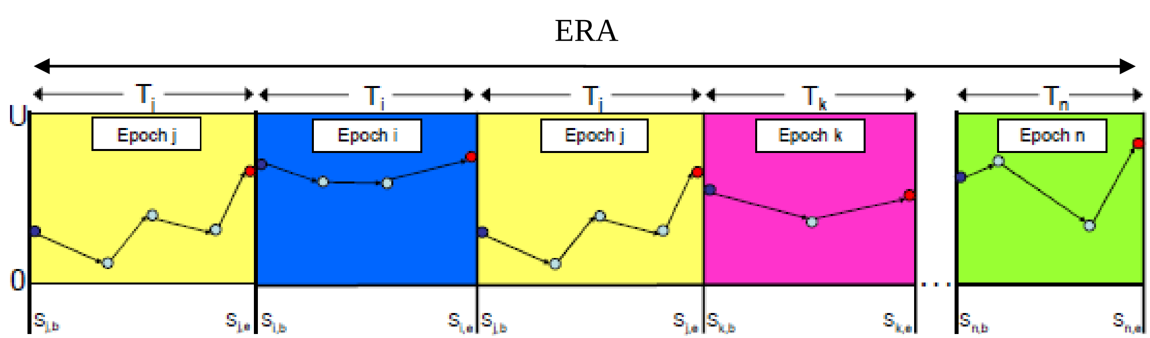


Figure 3: EEA Example (Ross A. M., 2006)

In 2008, Brown and Eremoenko developed a method of assigning a value to space system designs called Value-Centric Design (VCD). VCD uses random variables to add uncertainty to NPV calculations. With the introduction uncertainty, VCD generates a more accurate design value (Ryan, Jacques, & Colombi, 2011; Brown & Eremenko, 2008). Ryan, Jacques, & Colombi (2011) claim random variables only slightly increase the accuracy of the design value, however, the accuracy of VCD could be improved by using distributions based on historic data (Ryan, Jacques, & Colombi, 2011). Therefore, Ryan, Jacques, & Colombi (2011) used Brown and Eremoenko's VCD and developed a method called Current Expected Value Lifecycle Cost (CEVLCC). CEVLCC generates the life-cycle costs of a design over a range of important potential events. First, CEVLCC defines a list of future demand deviation the design may encounter. Then, CEVLCC creates probability distribution functions to determine key costs and parameters. Lastly, cost estimates are generated for all combinations of events. These steps are completed for each design alternative, and the design with the lowest CEVLCC is chosen. The benefits of CEVLCC are that it allows design evaluation based a predetermined set of demand deviations. The disadvantages are that the set of deviations only accounts for a small range of potential demands . Also, CEVLCC has undergone limited trials and remains unvalidated (Ryan, Jacques, & Colombi, 2011).

In 2011, de Neufville and Scholtes published "*Flexibility in Engineering Design*," which discusses in detail the potential for flexibility. Written for engineering as a whole, the book contains a large of amount material that can apply to facilities – including the four-phase process the authors created to evaluate and select flexible designs. The four phases of the de Neufville and Scholtes (2011) process are estimating distributions, identifying candidates, evaluate alternatives, and implementation. The first phase is to estimate a distribution of demand, which consists of two steps, generating ranges of demands and building a model. The second phase involves creating designs that have the ability to adapt to a range of potential demands. The third phase involves Monte Carlo simulation (MCS) to create thousands of possible lifecycles using the demand distributions. MCS "is a numerical process of repeatedly calculating a mathematical or empirical operator in which the variables within the operator are random or contain uncertainty with prescribed probability distributions" (Ang & Tang, 2007, p. 200). Then, for each potential lifecycle, each design alternative is valuated using lifecycle performance indicators such as NPV. The last phase is the implementation of the best design alternative (de Neufville & Scholtes, 2011).

de Neufville and Scholtes' (2011) process provides a method to evaluate multiple design alternatives. The method is adaptable, considers uncertainty, and uses lifecycle costs instead of fixed estimates. There are two significant obstacles to applying de Neufville and Scholtes' method to facility designs. First, the authors created only the basic stepping-stones of the method, so that it would apply to a majority of engineering systems. As the authors created the method for engineering systems and not facilities, the method will require many adjustments in order to apply the process to facilities. While de Neufville and Scholtes did provide case studies on facilities, they often skipped or did not explain key steps. For example, a case study on a parking garage used a percentage of uncertainty related to a point estimate instead of using historic data to generate a range of uncertainties. The addition of a historically generated range of uncertainties may completely change how a design alternative performs. Second, the level of analysis involved in de Neufville and Scholtes' method requires complete or nearly complete facility designs. As a result, design evaluations using this method require lots of effort, time, and funding, because of this funds limit the number of alternatives and, the probability of choosing a suboptimal design increases (Cardin & de Neufville, 2013).

Cardin and de Neufville (2013) proposed the concept of a design catalog to reduce the amount of resources dedicated to de Neufvill and Scholtes' four-phase method. A design catalog is a set of design alternatives or design characteristics that addresses a range of demand uncertainties. For facilities, a design catalog contains a large number of completed facility design that perform efficiently given high amounts of uncertainty. A design catalog can supplement or replace the design alternatives. Thus reducing the time, cost, and effort of creating new designs. Creating a full design for the catalog requires a large amount of resources. Therefore, design catalogs are not worth the investment unless there is high potential for multiple design evaluations using the same catalog (Cardin & de Neufville, 2013). Use of design catalogs may also lead to the "flaw of averages," due to the limited number of designs in the catalog and designs may not specifically address the demands of a facility.

Cost Estimating Systems

A major issue in evaluating design alternates is that each alternative requires a complete or nearly complete design. The amount of time, effort, and cost required to create multiple designs reduces the effectiveness of design evaluations because it limits the number of design alternatives (Cardin & de Neufville, 2013). The design valuation methods require full designs for generating accurate cost estimates for the initial design, operational, and modification costs. An alternative to creating a full design is to use cost-estimating systems. Parametric estimating is a widely used method for estimating product cost (Rush & Roy, 2000). Parametric cost estimating (PCE) uses physical facility parameters such size, number of floors, and type of building to develop accurate cost estimates (Meyer & Burns, 1999). Parametric cost estimating systems such as RSMeans and Parametric Cost Engineering System (PACES) software are capable of generating accurate initial construction cost and modification cost estimates using minimal and simple facility characteristics. For example, Appendix B: PACES Initial Construction, Addition, and Modification Estimation Process shows that the initial construction costs of facility can be estimated using the facility location, type, size, and number of stories. While, RSMeans and PACES are not capable of generating operational costs, other parametric cost estimating systems such as Whitestone's CostLab software was specifically create to predict operational cost.

Table 2 lists and describes the capabilities of several different PCE systems. PCE systems are valuable tools and can be used to significantly reduce the amount of resources dedicated to design evaluations.

Table 2: PCE Systems and Capabilities

PCE System	Capability
PACES	Can estimate initial facility costs and modification costs based of department of defense facility histories.
RSMeans Online	Can estimate initial facility costs.
Conedison Energy Cost Estimator	Can estimate annual facility energy costs.
CostLab Pricing	Can estimate maintenance and repair costs.

Conclusion

This literature review supports the evaluation of design alternatives and demonstrates the potential value of flexible design. Robustness and flexibility were defined and it was described how they are desired properties of a facility but lack a understanding or accepted definition in the research community. General and improve methods were discussed that have the capability to evaluate multiple facility designs whether they be standard, flexible, or robust. The general methods, however, did not capture the uncertainty associated with future facility demand changes. The improved methods of EEA, VCD, and MCS have the capability to evaluate multiple designs and capture the uncertainty of future demands. However, each of the improved design evaluation methods require substantial amounts of time to generate LCC estimates. In order the reduce the amount of time required PCE systems can be used to generate LCC with minimal and simple facility characters.

Choosing the correct design for Air Force facilities can increase the performance and decrease the LCC incurred in operating these facilities. A review of the literature shows that there are no methods specific to facilities for evaluating and selecting different lifecycle designs; rather, general methods must be adapted for use in evaluating these facility designs. EEA, developed by Ross (2006), is a method for selecting the lowest cost path. The epoch and era concepts increases the accuracy of EEA demand predictions. de Neufville and Scholtes' (2011) method of NPV simulation analysis uses the power of MCS to evaluate designs based on thousands of potential lifecycles. Both of these approaches require multiple completed facility designs to determine LCC. Using a

PCE system to estimate LCC based on simple facility parameters will reduce resources dedicated to designing multiple facility design alternatives.

III. Methodology

Introduction

This chapter discusses a six-step methodology used to answer the two research questions. The first step of methodology focuses on collecting modifications and additions of Air Force facilities. The facility histories were then used to predicted the modification and additions that a new facility may experience. Then parametric cost estimating systems were used in combination with linear regression to create formulas that attempt predict facility lifecycle demands and estimate the LCC of standard, flexible, and robust designs. Then each of the facility modification and addition formulas, as well as the cost estimating formulas were verified and validated to ensure accuracy. Lastly a LCC Monte Carlo simulation (MCS) was created and ran for every combination of the facility inputs (size, category code, and number of stories). The remainder of this chapter will discuss each of these steps in detail and discuss the purpose of creating the MCS.

Methodology Development

In an effort to focus on LCC, ranges of potential facility demands, and evaluation of multiple facility designs, this research methodology will have six steps:

Step 1: Historic Facility Data Collection

Step 2: Facility Demand Prediction

Step 3: LCC Cost Estimation

Step 4: Verification and Validation

Step 5: Facility Lifecycle Simulation

Step 6: Analysis

These six steps will use three changes in the current facility design process that are essential to evaluating flexible facility design: focusing on LCC, generating multiple potential facility demand lifecycles, and evaluating multiple facility designs. However, the main goal of the methodology is to answer the two research questions:

1) When comparing flexible, robust, and standard designs for an administrative facility, which alternative represents the greatest LCC savings to the Air Force?
2) Under what facility characteristics does flexible, robust, and standard designs result in the lowest LCC?

The best method to answer these two research questions is to build a MCS that can estimate the LCC of multiple facility designs, Step 5, which has the capability to compare the LCC of multiple design alternatives across a range of potential facility demands for a given time-period. By varying the simulation inputs, Step 6, this research will provide the LCC for each facility design over a wide range of facilities. In combination with an analysis of variance (ANOVA) test, which compares the LCC means of each facility design, the results will answer the second research question. Finally, by combining the results of all the MCS outputs and performing another ANOVA test on these aggregate results, the first research question can be answered.

Step 1: Facility Data Collection

In order to build a model that answers the research questions, the demands that a new facility may experience over the evaluation time-period must be determined. The Air Force does not currently have a method of determining future facility demands.

Therefore, this research collected project data on Air Force administrative facilities in order to predict facility demands. However, facilities experience many different types of demand changes. The key is to focus on the facility demands that would result in a cost decrease or increase for one of the three types of designs that were evaluated: standard, flexible, and robust. The increase in facility size from a facility addition will effect each design differently. A robust design would not require an addition because it was built larger initially. A flexible design was designed for the size increase but would still experience some cost. A standard design would experience an expensive addition project because it was not initially designed to grow in size. The system components of a standard design such as electrical panels will either have to be upgraded or replaced, in order to meet the demands of a larger facility size. Facility modifications made to a the facility's communication, electrical, HVAC, and plumbing system would also affect the LCC of each design but here an assumption was made that only the standard design would experience increased costs. This assumption was made since both flexible and robust design are initially built with larger facility systems that have excess capacity and would not need to be upgraded or modified. This research concentrated on five demands: facility addition as well as communication, electrical, HVAC, and plumbing system modifications. Therefore, to predict additions and the system modifications, data was collected on the construction of an administrative facility and for every modification and addition that occurred in its service life.

The Air Force refers to all the different types of facilities through a six-digit category code (CATCODE) and administrative facilities begin with the digits "610" (United States Air Force Civil Engineers, 2012). With this information, all unclassified facilities that have “610” administrative space were collected from Air Force Real Property Assets Database (RPAD). The RPAD provides the entire Air Force population of facilities that have “610” administrative space, but this research attempted to focus only on facilities where the majority of the facility area was administrative space. From the RPAD the following “610” facility information was obtained: installation, facility number, CATCODE, facility size, and the date the facility was placed in service. However, the list of RPAD facilities is based on facilities that have square feet (sq-ft) dedicated to administrative use. Therefore, it is likely that the small size facilities on the RPAD have administrative space but the majority of the facility space has a different CATCODE. Since the RPAD does not have a means of identifying the CATCODE that makes up a majority of the facility space, facilities less than 1,000 sq-ft were removed. In addition, the RPAD does not contain the project data of all the modifications and additions that occurred while the building was in service nor does it include the number of stories in the facility.

Ideally, a system called Automated Civil Engineering System-Real Property (ACES-RP) should be used instead of the RPAD. ACES-RP would be able to determine the CATCODE that makes up a majority of the facility space and it contains the number stories in each facility. However, the process of gaining access to ACES-RP is longer than the research period. So the RPAD was used to collect the initial facility data and a new facility management called BUILDER® was used to collect the number of stories.

The Automated Civil Engineering System-Project Management (ACES-PM) was used to collect the modification and addition projects for each of the administrative facilities identified from the RPAD. Modification and addition projects were identified in ACES-PM by a three-digit Fund Type code and the Fund Type codes used to identify facility additions and modifications are listed in Table 3. In addition to the Fund Type code, only projects that had a project status of completed or in construction were collected. The data collected from ACES-PM contained the installation, facility number, CATCODE, the facility area being modified, modification size, project year, project title, description, justification, and project remarks.

Table 3: ACES-PM Fund Type Codes

Fund Type	Description
522	Upgrade or Modernization
529	Minor Construction
341	Emergency Repair
321	Military Construction (MILCON)

The data from ACES-PM contains the history of projects for each of the administrative facilities; however, it does not identity whether an addition or specific modification occurred. The project information in ACES-PM contains project title, description, justification, and remarks sections which are used to determine what specification modifications or additions were accomplished. Therefore, the project title, description, justification, and remarks section were used to perform the keyword searches listed in Table 4 to identify additions or the type of modification. After the potential addition and modifications were identified, a quality check was performed to verify and refine the keyword search.

Table 4: Addition and Modification Keyword Identification

System Modification	Keywords
Addition	"*addition *", "*exterior*", "*foundation*", "*construct*"
Communication	"* comm*", "* CS *", "*phone*", "*internet*", "*computer*", "*audio*"
Electrical	"*outlets*", "*power*", "*elec*", "*feeder*", "*lights*"
HVAC	"*heating*", "*HVAC*", "*hvac*", "*cooling*", "* air c*", "* vent*", "*a/c*", "*crac *"
Plumbing	"* sinks*", "* dishwasher*", "*water*", "* kitchen*", "* boiler*", "*drains*", "*refrigerator*", "* ice*", "*latrine*", "*chiller*", "*shower*"

A history of modifications and additions was created by combining the RPAD administrative facility data with ACES-PM project data a history of additions and modifications was created. From these facility histories, a stratified random represented sample was taken. The population of facilities was separated into age and size groups then converted into percentages per group. These percentages were used to ensure the random sample is representative of the population of facilities. Facilities were separated by age into groups based on 5-year periods. Size groups were determined by the distribution quartiles. The total number of age sample for each age period and for each size group must be greater than or equal to 30 samples in order to ensure the sample meets the requirements of central limit theorem and the means of the sample can be approximated by a normal distribution.

Table 5 is an example of the sampling plan. A sample size of more than 30 enabled the use of the central limit theorem because each age and size group is a normal approximations of the population (McClave, Benson, & Sinchich, 2014).

Table 5: Random Representative Sample Plan

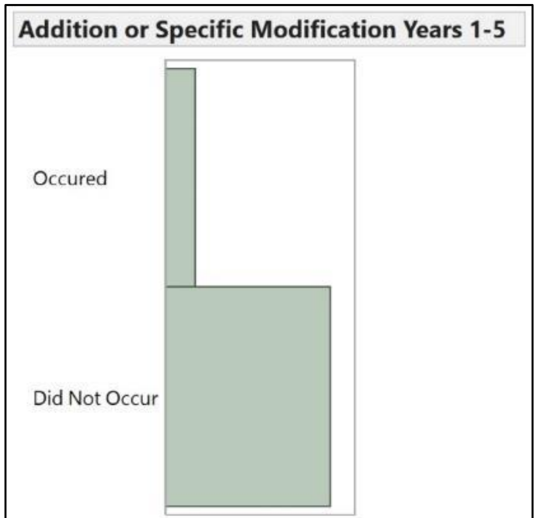
Age (Years)→ Size (sq-ft) ↓	**Age≤5**	**5<Age≤0**	**10<Age≤15**	**15<Age≤18**	**Total Size Sample**
25% of the Population					≥30
Median of the Population					≥30
75% of the Population					≥30
Total Age Sample	≥30	≥30	≥30	≥30	Overall Total≥120

The data collection step resulted in sample of administrative facilities and their addition and modification projects. This data was used to predict the demands of new administrative facilities. However, the ACES-PM system only contains project data from 1996 to 2014. As a result, the MCS is limited to only predicting 18-years' worth of facility demands. While predicting the overall lifecycle costs of each facility design would be ideal, an 18-year prediction estimate is sufficient to show the advantages of each design.

Step 2: Facility Demand Prediction

The facility demand prediction step used the collected facility history to determine the probability of an addition and modification occurring in an 18-year period and determines the size of addition or modification. Knowing the probability of an addition or modification occurring in a given period enabled the MCS to predict the period of time in which an addition or modification occurred, and knowing the size of an addition or modification provided the information need to estimate a cost.

By converting the facility history into binary variables, logistic regression was used to identify predictive variables and determine the probability of modification occurring in a given period. In order for the logistic regression to be employed, a sufficient number of modifications or additions need to have occurred. In this case, more than 10 percent of the sampled facilities must have experienced a modification or addition. For example if the sample size 100 facilities and the researcher is attempting to predict if an addition may occur, then 10 of the 100 facilities must have experienced additions within the timeframe. In addition, if a modification or addition occurs early in the lifecycle it may affect the probability on another modification or addition occurring in the remainder of the lifecycle. For example if an HVAC modification occurs in the first 5 years it may change the probably of a modification occurring again in year 5 through 10. Therefore, modification and addition periods were kept small by ensuring that the occurrence percentages were below 20 percent. Thus, not only does the number of occurrences need to be greater than ten percent, but it must also be less than twenty percent. Figure 4 shows an example distribution output from the statistical software JMP® that meets the requirements of this research because the frequency of the modification or addition occurrence is 15 percent which is between the research criteria of 10 percent and 20 percent. These logistic regression criteria improved the accuracy of the logistic regression formula to predict the probability of a modification occurring.



Frequencies

Level	Count	Prob
Did Not Occur	17	0.85000
Occured	3	0.15000
Total	20	1.00000

Figure 4: Binary Distribution Example

Logistic regression, in combination with a pseudo-random number generator, is used to predict whether an addition or modification occurs within a given time-period, but does not predict the specific year a modification occurred. For example, Figure 4 has a time period of one to five years, therefore logistic regression would only predict if a modification or addition occurs within the 5 year-period but would not be able to predict which year the addition or modification occurred in. Therefore, the number of events occurring in the specific year, divided by the total number of events in the time period, was used to determine which specific year the addition or modification occurred. For example, Table 6 shows three additions or modifications occurred one in each of years two, three, and five, therefore, there is a 33 percent chance that a predicted modification or addition will occur in years two, three, and five. Determining the specific year in which an addition or modification will likely occur is necessary for three reasons: 1) Assuming an addition occurred at the end of the period favors standard and flexible designs through decreased annual operational costs; 2) assuming an addition occurred at the beginning of the period increases operational costs for standard and flexible designs in favor of robust designs; and 3) an addition increases the size of the facility which affects the modification costs from that year to the end of the time period. Following this process, the probabilities for a modification and when it might occur were determined.

Table 6: Determining Modification or Addition Year Example

	Year 1	Year 2	Year 3	Year 4	Year 5
Addition or Modification occurred	0	1/3	1/3	0	1/3

With probability of an addition or modification modeled for each year of the 18-year evaluation period, the size of each addition and modification was also modeled in order to estimate the cost for each design. Ideally, a linear regression would be used to determine the size of an addition or modification. However, even though the ACES-PM system is capable of recording an addition or modification size, the ACES-PM database does not require a value to be entered. As a result, few projects have an accurate addition or modification size. However, over 50 percent of additions sizes are tracked in ACES-PM which is makes it possible to use a Weibull distribution to represent the size of any additions that occur. In order to use the Weibull distribution, it must pass a Goodness-of-Fit test using a 0.1 alpha. Due to the Weibull distribution deviation being small and roughly the same across the distribution and not focused in a specific section, a Cramer-

Von Mises Goodness-of-Fit test was performed (Arnold & Emerson, 2011). For facility system modifications, the percent of a facility's system that is modified (which is rarely entered into ACES-PM) is represented by a high and a low value. For this research, the mean and median addition sizes of the sample will represent these two percentages. Since the distribution is skewed right in all cases, the median was used to represents a small modification size and the mean was used to represent a large modification size.

Step 3: Determine LCC estimates for each design

LCC costs consist of initial construction, addition, modification, and operational cost estimates across an 18-year period. The Air Force currently does not have the capability to generate LCC easily and accurately. However, the Air Force does have access to a parametric cost estimating system called PACES©, which can accurately estimate initial construction, additions, and modification costs with basic facility inputs such as size, type, and number of stories. Another parametric cost estimating system similar to PACES, called CostLab, can provide accurate operational costs. By using CostLab and PACES, accurate LCC estimates were generated for each facility across 18-years. While the two parametric cost estimating systems provided LCC estimates for each sample facility, it did not provide a method of estimating the LCC in the MCS. Therefore, after LCC estimates have been determined for each facility in the sample, a linear regression was performed to estimate each LCC based on the facility size. The result was multiple linear and polynomial formulas that are able to estimate the LCC of three administrative facility designs.

Assumptions

Location affects the LCC of a facility design. However, the goal of this research is not to provide LCC of a facility but rather to show the relative difference between the LCC of multiple designs. Since location cost factors affect all the design alternatives the same amount, an assumption was made that as long as the location was consistent throughout both estimating systems, the cost estimates would change, but the ranking between design alternative remain the same. Therefore, for both cost estimating systems, Dayton, Ohio was used as the location.

The sample of administrative facilities contained the inputs required for both cost-estimating systems; however, there is no method of determining if a facility is a standard, flexible, or robust design. Since Air Force Instruction (AFI) 32-1021 (2014) only requires only three to five years of future planning (Abrol, 2014) and receiving funds and constructing the facility may take three to five years, an assumption was made that all sample facilities were treated as standard facility designs. This assumption may slightly slant results in favor of standard designs because robust designs would have a lower probability of addition or modification occurring, and treating a robust design as standard design may lower the probability of standard design experiencing an addition or modification in this research.

Flexible and robust facilities are designed with extra capacity, but for increased facility size, that capacity can be represented in two ways. A facility could be designed for a vertical size increase, such as adding an additional story to a facility or a facility could be designed for a horizontal increase, which increases the building’s footprint but does not affect the number of stories. From the facility data it is not possible to tell whether an addition was vertical or horizontal. Therefore, it is not possible to determine the number of stories for a vertical addition and without the number of stories, PACES cannot provide a cost estimate. However, PACES can provide a cost estimate for all horizontal additions. Therefore, all facility additions were assumed to be horizontal additions that do not affect the number of stories.

Initial Facility Construction Estimates

To generate initial construction cost estimates for standard, flexible, and robust designs, PACES requires three inputs: facility size, number of stories, and CATCODE. The current facility sample provides all the required inputs to generate cost estimates for standard designs but does provide the facility size needed to generate robust and flexible construction estimates. To determine the size that a robust design should be constructed at, and that flexible design should be able to grow to, the size of additions that the sample facilities experienced was used. Since standard design does not consider any future requirement, and since having extra capacity may increase the number and size of additions, a robust and flexible design was evaluated at the facility size plus the mean and at the mean plus one standard deviation of all the addition sizes recorded from the facility sample. These two size facility sizes provide a low and high facility size for both the flexible and robust facility designs. Overall, the three design types provide results for no future planning, average future growth, and large future planning across an 18-year period.

Facility construction costs for standard, robust average size, and robust large size designs are generated in PACES for each of facility samples. Then a level-two cost report built into PACES provides the breakdown of costs into Uniformat II facility group elements shown in Table 7. Since flexible designs are standard designs that have the capacity to grow into robust designs, the cost report was used to determine the costs of flexible average and large designs. The foundations, superstructure, stairs, and facility systems would all be built larger initially in order to expand later in the lifecycle, therefore, the robust design cost was used as flexible cost estimates in those sections. The remaining sections would not be built larger initially, so standard design costs estimates were used. Table 7 shows the Uniformat II facility group elements and contains the elements of robust and standard designs that were used to estimate flexible design costs.

Table 7: Uniformat II Facility Group Elements

A	**SUBSTRUCTURE**		**Flexible Cost**
	A10	FOUNDATIONS	Robust Design
B	**SHELL**		
	B10	SUPERSTRUCTURE	Robust Design
	B20	EXTERIOR ENCLOSURE	Standard Design
	B30	ROOFING	Standard Design
C	**INTERIORS**		
	C10	INTERIOR CONSTRUCTION	Standard Design
	C20	STAIRS	Robust Design
	C30	INTERIOR FINISHES	Standard Design
D	**SERVICES**		
	D10	CONVEYING	Robust Design
	D20	PLUMBING	Robust Design
	D30	HVAC	Robust Design
	D40	FIRE PROTECTION	Robust Design
	D50	ELECTRICAL	Robust Design

Addition Costs

For standard designs, additions are represented as new facilities that are attached to the existing facility. Therefore, the initial construction estimates for each sample facility may also be used to determine addition cost estimates. However, no sample facility is less than 1,000 sq-ft and the small sizes of facility estimates would not be as accurate when represented by a linear equation because larger size facility estimates have a higher influence on the slop of the formula. Therefore, the initial construction cost estimates were used for additions greater than 2,000 sq-ft and cost estimates were generated from PACES for additions less than or equal to 2,000 sq-ft. A minimum of ten cost estimates are required for facilities with one story, two stories, and greater than two stories. A Uniformat II group element cost report was used to determine the cost of additions for flexible designs. Whereas a standard design would experience addition costs for each of group elements listed in Table 7, flexible designs would only experience costs in areas that were not initially constructed with extra capacity; exterior enclosure, roofing, interior construction, and interior finishes. By using the construction cost estimates for additions greater than 2,000 sq-ft and PACES cost estimates for facilities less than or equal 2,000 sq-ft, there is adequate cost data to fit a distribution that was able to estimate the cost of an addition for each of the design alternatives.

Modification Costs

Modifications occur when a standard design needs to increase the capacity of facility system. However, flexible and robust facility systems such as HVAC, communication, plumbing, and electrical systems, are initially built with excess capacity. Therefore, flexible and robust facility designs do not experience upgrades and increases.

Using the mean and medians of the sample facility data standard design cost estimates were generated in PACES for communication, electrical, HVAC, and plumbing systems.

In order to generate modification cost estimates, the PACES system requires the initial construction cost of each of the facility samples to be stored in the system. Since PACES was used to generate the initial construction cost of each sample facility, this data was already in the system and only had to be selected. Then, using the building renovation wizard built into PACES, the percent of the facility that is being modified and system being modified was entered into the software. For example, Figure 5 shows twenty-two percent of the facility's electrical system is being modified. In addition, for any system modification, there will likely be some amount of structural repair as a result modification costs include minor structural repair costs. Therefore, for all modification there is an assumed minor level of structural renovation.

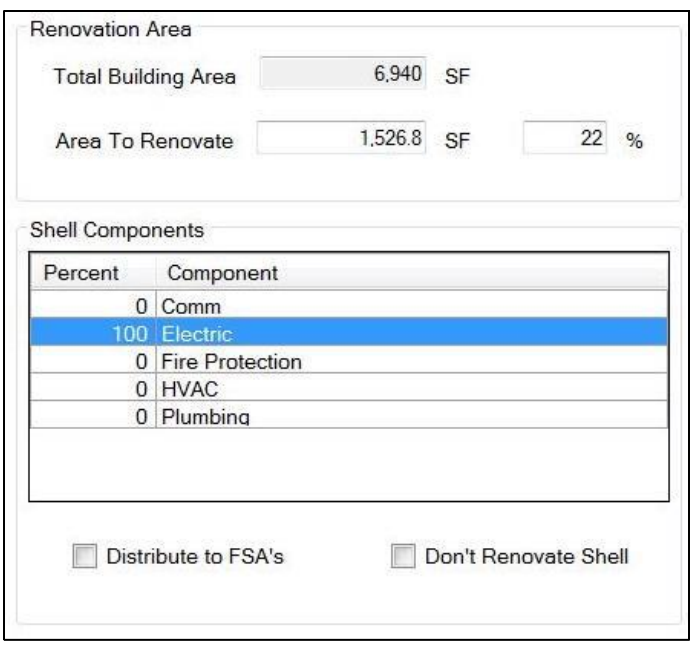


Figure 5: PACES Modification Wizard

Operational Costs

PACES is a quick and accurate method of generating cost estimates for facility construction, modification, and repairs; however, it does not have the ability to generate operational cost estimates. Therefore, another system called CostLab, another parametric cost estimating system similar to PACES, was used to generate operation cost estimates. CostLab operational costs consist of maintenance and repair, recapitalization, custodial, energy, grounds maintenance, management, pest control, and refuse costs. Since these operational costs are only different between standard, flexible, and robust designs due to the facility size, one formula was created that uses facility size to generate cost estimates for each design.

CostLab operation estimates were generated for each sample facility using the facility size, the year the facility was placed in service, the number of stories, and an assumed office facility type, which was the best approximation of an administrative facility. After all sample facilities were in the CostLab database, a CostLab report was generated that contains a five-year operational cost estimate for each facility sample. One limitation to CostLab is that it only provides future operational cost estimates out to five years. For example, for a ten year old facility, CostLab provides operational cost estimates for years eleven through fifteen. It does not provide the operational costs for years one through ten since they would have already occurred and would not need to be estimated. In addition, the software has the capabilities to provide operational cost estimates for the remaining service life; however, those estimates are only available with the purchase of an annual license. Therefore, CostLab only provides the operational cost estimates for each sample facility from years 2015 to 2019. This limitation was minimal because the sample facilities range in ages from new to eighty-years old. By aligning the facilities ages, operational cost estimates were determined for operational years one through eighteen.

Estimating Costs

Once the sample facilities had initial construction, modification, addition, and operational cost estimates for each design, linear regression or polynomial regression was used to fit a straight line or polynomial formulas, respectively, to each set of cost estimates. This was done by plotting the cost estimate by facility size. JMP® software was used to fit linear and polynomial regression lines through 123 of the 184 sample facilities cost estimates and the remaining 61 sample facilities were used to verify and validate the linear and polynomial formulas. For each of the linear and polynomial regressions the adjusted coefficient of determination (R^2) values were recorded. The adjusted R^2 values show the proportion of the parametric cost estimate variation that is explained by the facility size (McClave, Benson, & Sinchich, 2014). In addition, influential cost estimates cause inaccuracies in the linear regression, so Cook's distance values were calculated for each estimate and cost estimates were group to together by size or number of stories until all Cook's distance values were less than one. In some linear regressions, the Cook's distance values of a cost estimate did not fall below one and this occurred the cost estimate was excluded. No more than two cost estimates were excluded from all linear regressions. Then the overall P-values of each regression must be less than the alpha of 0.1 and all p-values of regression inputs must be less 0.1 divided by the number of inputs in the regression. The linear and polynomial regressions provided formulas that were used in the MCS to estimate LCC for standard, flexible, and robust designs across 18-years.

Step 4: Verification and Validation

The goal of the verification and validation step is to confirm the accuracy of both the logistic regression facility demand formulas and the cost estimating formulas, and to calculate triangle distributions that were used in the MCS to represent the uncertainty of the cost estimates. Twenty percent of the cost estimates were not used during the linear and polynomial regressions and during the logistic regression. For the verification and validation step, the entire sample data was used to validate each formula.

Logistic Regression

The logistic regression produces to a formula similar to Equation 1 that is used to predict the probability of an event occurring.

$$p = \frac{e^{(\beta_0+\beta_1 X_1+\beta_2 X_2+\cdots+\beta_n X_n)}}{1+e^{(\beta_0+\beta_1 X_1+\beta_2 X_2+\cdots+\beta_n X_n)}} \qquad \text{(Equation)}$$

where

$$p = probability\ of\ occurance$$

$$\beta_n = Parameters\ of\ the\ model$$

$$X_n = Predictor\ variable\ occured\ (0/1)$$

For the verification and validation of the logistic regression formulas, if the probability of an event occurring is greater than or equal to 0.5 it means the MCS predicts that the event will occur. There are only four possible outcomes as shown in Table 8. To ensure an accurate simulation, the criteria for the verification and validation was the total number of correct outcomes divided by the sample size must be greater than seventy-five percent.

This criterion helped ensure that the model was seventy-five percent accurate at predicting whether a modification or addition will likely occur in a given period. However, with a large sample size and low probability of a modification or addition occurring most of the accuracy of the formula was in predicting that no event occurred. Therefore, another criterion was that the number of correctly predicted events divided by the number of event that was predicted to occur must be greater than twenty percent.

Table 8: Logistic Regression Outcomes

	Actual	Predicted
Correct Outcomes	Event Occurred	>=0.5
	No Event	<0.5
Incorrect Outcomes	Event Occurred	<0.5
	No Event	>=0.5

LCC Estimates

The linear and polynomial formula are used to represent LCC and are not limited to binary outcome like the logistic regression formulas are. Therefore, it is important to know how far off the cost estimate was from the actual cost. The inaccuracy or uncertainty of the cost estimate is minimized in the LCC simulation through triangular distribution which provide a range of uncertainty to each estimate. The mean absolute percentage error (MAPE) shown in Equation 2 was used to ensure the cost estimates are an appropriate approximations. The overall MAPE must be less than to ten percent to be used in the MCS. In addition, since the cost estimates are used for multiple sizes of facilities, and a cost estimating formula can be more accurate with small facilities and less accurate with large facilities. Therefore, for each size or number of stories group, the MAPE must be less than twenty percent. This criterion helps ensure that the cost estimates accuracy is not slanted to one facility size over another.

$$MAPE = \sum_{i=1}^{n} \left(\frac{|A_i - E_i|}{A_i}\right) \frac{100\%}{n} \qquad \text{(Equation)}$$

where

$$n = total\ number\ of\ samples$$

$$A_i = Parametric\ Estimated\ Cost\ per\ sample$$

$$E_i = Research\ Estimated\ Cost\ per\ sample$$

Limitation

For this research, the actual costs are unknown because parametric cost estimates were used to generate the linear and polynomial formulas. Future research can improve the accuracy of the MCS by using actual facility costs.

Uncertainty in Cost Estimates

For each cost estimate there is uncertainty and in a simulation that uncertainty can be capture. Therefore, in order to capture the uncertainty of each of the linear and polynomial cost estimating formula, triangular distributions were used. The triangle distribution was created using the maximum, minimum, and mean of the percent error formula shown in Equation 3. With the triangle distribution, the MCS provided a more representative estimation of the cost estimate accuracies.

$$1 - PE_i = A_i - E_i \qquad \text{(Equation)}$$

Where

$$PE_i = Percent\ Error$$

$$A_i = Parametric\ Estimated\ Cost\ per\ sample$$

$$E_i = Research\ Estimated\ Cost\ per\ sample$$

Step 5: Facility Lifecycle Simulation

The facility lifecycle simulation used in this research was derived from de Neufville and Scholtes' (2001) combined with Ross's (2006) EEA concept. The MCS uses the user inputs of facility size, CATCODE, and number of stories to estimate the initial construction cost of standard, flexible average size, flexible large size, robust average size, and robust large size facility designs and estimate operational costs for an 18-year period. Then, logistic regression formulas determine whether additions or facility modifications are likely to occur in the 18-year facility lifecycle, and if a modification is predicted to occur, the median and mean were used to represent the size of the modification and the linear formulas were used to estimate the cost. The size of additions is determined by a Weibull distribution and linear and polynomial formulas provide cost estimates for the standard and flexible facility designs. For all cost estimates, a triangular distribution was used to represent the uncertainty inherent in each estimate. At the end of the 18-year period, Equation 4 through 6 were used to estimates the LCC of each design. Then the simulation generates 1000 potential facility lifecycles with different facility demands and costs. The output of the simulation was 10,000 facility lifecycles with LCC for each of the following six designs: standard with median modification, standard with mean modification, flexible with average addition size, flexible with large addition size, robust with average initial size, and robust with large initial size.

$$LCC_S = C_S + \sum O + \sum M + \sum A_S \quad \text{(Equation)}$$

$$LCC_F = C_F + \sum O + \sum A_F \quad \text{(Equation)}$$

$$LCC_R = C_R + \sum O \quad \text{(Equation)}$$

Where

$LCC_S = Lifecyle\ Cost$

$C_S = Initial\ Cosntruction\ Cost$

$O_S = Operational\ Cost$

$M = Modificaiton\ Cost$

$A_S = Addition\ Cost$

$_S = Standard\ Facility\ Design$

$_F = Flexible\ Facility\ Design$

$_R = Robust\ Facility\ Design$

Step 6: Analysis

From the output of the facility lifecycle simulation the design alternative that results in the lowest LCC was determined; however, the output is specific to one specific set of simulation inputs of size, CATCODE, and number of stories. Therefore, in order to answer both research questions, the inputs of the LCC simulation were varied and the results were analyzed. The MCS was executed for each set of inputs that the logistic regression determined to be predictive. Then an ANOVA was performed to determine which simulation inputs and designs have significant differences. The individual

ANOVA results was used to answer the second research question, which was to determine the simulation inputs that result in flexible, robust, and standard designs having the lowest LCC. Then the results from each execution was combined to answer the first research question, which was to determine which design alternative represents the greatest LCC saving to the Air Force.

IV. Analysis and Results

Chapter Overview

This chapter presents the results and analysis of each of the six steps described in the methodology. The results are displayed through figures and tables located in this chapter or in the appendixes. Each figure and table is explained and a discussion of the of each describe how contribute to the simulation.

Historic Facility Data Collection

The entire population of administrative facilities was collected from the Real Property Assets Database (RPAD) using category codes (CATCODEs) that began with "610" and where the facility size was greater than 1,000 sq-ft. From the RPAD facility data, 400 administrative facilities were identified. The distribution shown in Figure 6 shows the RPAD facilities distributed by size and age. The sample of facilities are divided into four categories: less than 5 years, between 5 and 10 years, between 10 and 15 years, and between 15 and 18 years. To categorize by size, the sample was divided into quartiles (Table 9) and this stratification established the four size groupings displayed in Table 10. The facility size groups for this research are shown Table 10 and roughly align with the quartiles but are slightly shifted to capture the trends of the distribution.

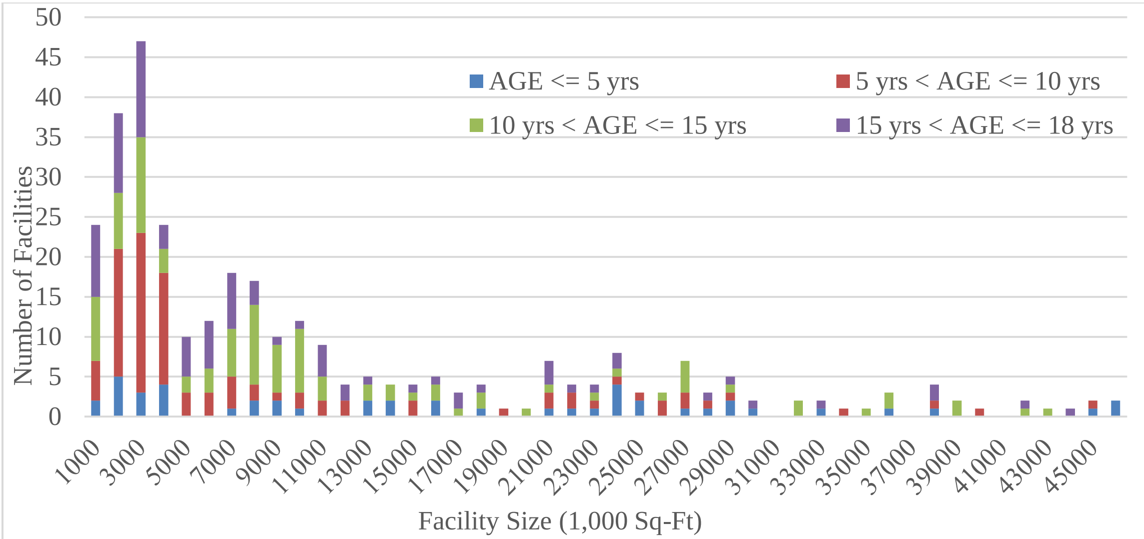


Figure 6: Distribution of RPAD Facilities

Table 9: Quartiles of the RPAD Facilities Distribution

Quantiles		
Percent		**Size**
100.0%	maximum	627231
75.0%	quartile	24439
50.0%	median	8304
25.0%	quartile	3600
0.0%	minimum	1068

Table 10: RPAD Facility Size Groups

Facility Size Groups	
Group 1	Size<= 4000 sq-ft
Group 2	4000<Size<= 9000 sq-ft
Group 3	9000<Size<=25000 sq-ft
Group 4	25000 sq-ft <Size

Table 11 organizes the population of 400 administrative facilities according to age groups and size groups. Using all 400 facilities from the RPAD population is not needed for several reasons. First, a sample of 400 facilities would require a long execution period in deriving the requirementss needed for the simulation. Second, the complete population is not necessary for predicting facility demands or estimating the cost of Air Force facilities. Therefore, a stratified random representative sample of facilities was selected. This random selection was completed through calculating the percentages of the population in each age and size group. These percentages were used to determine how many facilities should be selected for each individual age and size combination in the sample. Using the central limit theorem (CLT) to ensure the sample can be assumed to have a normal distribution of the mean representitive of the population, the targeted total number for each size and age group was greater than 30 facilities. Table 12 shows the resulting sample of facilities was broken up into size and age groups.

Table 11: RPAD Facility Age and Size Counts (400 Facilities)

RPAD Population						
AGE (years) → Size (sq-ft) ↓	**AGE <= 5**	**5 < AGE <= 10**	**10 < AGE <= 15**	**15 < AGE <= 18**	**Age Unknown**	**TOTAL**
1000 < Size <= 4000	15	34	32	35	1	**117**
4000 < Size <= 9000	5	22	28	31	12	**98**
9000 < Size <= 25000	11	19	31	26	3	**90**
25000 < Size	23	24	26	20	2	**95**
TOTAL	**54**	**99**	**117**	**112**	**18**	**400**

Table 12: Facility Sample Age and Size Counts

Research Sample					
AGE (years) → Size (sq-ft) ↓	**AGE <= 5**	**5 < AGE <= 10**	**10 < AGE <= 15**	**15 < AGE <= 18**	**TOTAL**
1000 < Size <= 4000	9	12	7	7	**35**
4000 < Size <= 9000	2	7	9	11	**29**
9000 < Size <= 25000	8	6	8	7	**29**
25000 < Size	10	7	8	5	**30**
TOTAL	**29**	**32**	**32**	**30**	**123**

The sampling process ensures that the sample facilities are representative of the RPAD population, even though the sample size is 34.2 percent of the population (400 facilities). This sample is representative of the population because the sample distribution will match the population percentages for each age and size group. However, as Table 12 shows during the research process, two facilities were removed due to inaccurate facility records and this caused three age and size group totals to fall to 29. While, these size and age groups are below the 30-facility CLT requirement, the CLT number of 30 is a rough estimate of the sample size needed to assume a normal distribution of the mean. Therefore, this research assumes 29 facilities is an acceptable facility sample size so as to apply the CLT. Figure 7 shows the age and size group breakdown of the sample facilities as compared to the population. The percentages are roughly equivalent in each category, and since the facilities were randomly selected, this research can conclude that the sample facilities are a random representative sample of the RPAD population. In addition to the 123 sample facilities, an additional 61 facilities were randomly selected from the RPAD population to use during the verification and validation process.

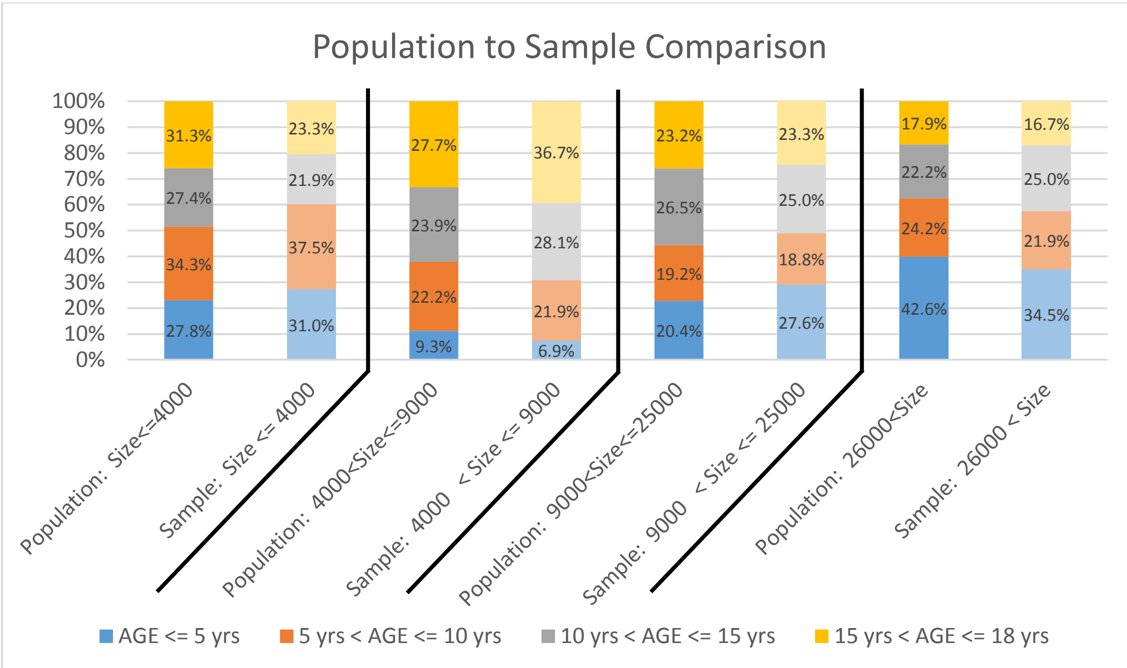


Figure 7: Population to Sample Comparison

The RPAD facility data does not contain the number of stories for each facility. Since this information is required for both predicting facility demands and during the LCC estimation process, a system called BUILDER® was used. Unfortunately, BUILDER® is a relatively new database and is still being populated. As a result, 169 out of 184 facilities are recorded in BUILDER® and the number of stories for each of the 169 facilities was added to the sample facilities data. The number of stories on the remaining 16 facilities had to be assumed in order to estimate the LCC for each facility. This research assumes that the missing sixteen facilities have close to the same distribution as the population with regards to the number of stories. Out of the 169 facilities 78.7 percent were one story, 16.0 percent were two story, and 5.3 percent had greater than two stories. A uniform random number from zero to one was assigned to each of the sixteen facilities. If the random number was less than or equal to 0.787 then the facility was assumed to be one story, if the random number was below or equal to 0.787, plus 0.16, then the facility was assumed to have two stories, and if the random number was greater than 0.787 plus 0.16, then the facility was assumed to have three stories. Since only one sample facility had more than three stories the maximum assumed number of stories was three. Having the sixteen assumed number of stories included in the logistic regression may cause inaccuracies in predicting facilities demands but the JMP® software can perform logistic regressions with some unknown data. The assumed number of stories for each of the sixteen facilities was only used for the cost estimating step of the methodology and the number of stories was left unknown during the logistic regression step.

Using the sample facilities, the modification and addition projects for each facility was collected from ACES-PM. However, ACES-PM only contains the last eighteen years of facility projects. Therefore, the MCS is limited to an eighteen year lifecycle. The ACES-PM projects were combined with the RPAD facility data to generate a history for each of the sample facilities. Then keyword searches and quality checks were performed to identify all communication, electrical, HVAC, and plumbing modifications as well as all facility additions that each sample facility experienced.

Facility Demand Prediction

To predict facility demands, three factors need to be addressed: the prediction of a system modification or addition, the year the predicted modification or addition occurs, and the size of the modification or addition. Logistic regression provided formulas that return the probability of each modification or addition occurring in a given period of time given the facility characteristics. However, in order to perform logistic regression, the predicted modification or addition needs to have occurred more than ten percent of the time in the given period. A maximum occurrence percentage is also necessary because more than one addition or modification may occur in a given period, and a modification or addition occurring in the lifecycle may affect the probability of another modification or addition occurring. For example, if an electrical modification occurs during the fifth year of a facility's lifecycle it may change the probability of another electrical modification occurring in the following year or the remainder of the facility lifecycle. Therefore, the percent of modification or addition occurring during the period of time must be less than twenty percent. Table 13 shows the year groups and the occurrence percentage for each system modification and additions.

Table 13: Addition and Modification Occurrence

Type →	Addition	HVAC		Communication			Electrical		Plumbing	
Period →	1-19	1-7	8-19	1-4	5-8	9-19	1-6	7-19	1-7	8-19
Count Occurred	18	13	16	13	14	13	13	17	13	13
Percent Occurred	0.146	0.106	0.130	0.106	0.114	0.106	0.106	0.138	0.106	0.106

Separate logistic regressions were completed for each of the systems year groups and the addition year group using the 123 sample facilities. For both the model and the individual factors to be statistically significant their respective p-values need to be less than or equal to the 0.1 alpha. The p-values will ensure that the overall probability is statistically significant and the each of the factors significantly affect the probability of predicting the occurrence of additions or modifications. Table 14 shows each logistic regression's p-values tests in the p-value columns and each of the overall p-values are below the alpha and each of the factor p-value are below the alpha divided by the total number of factors.. The estimate column contains the numbers that are used to generate each of the probability formulas by substituting each of the betas in Equation 1 with the corresponding number from the table. Table 15 contains the complete formulas that were used in the simulation.

Table 14: JMP® Logistic Regression Results

System	Period	n	Overall p-value	Parameter Estimates Term	Estimate	p-value
Additions	1-18	123	0.0077		-2.110	<.0001
				>2 Stories	2.110	0.0155
				HQ Base Level	2.110	0.0155
Comm	1-4	123	<.0001		-4.394	<.0001
				2 Stories	3.353	0.0026
				>2 Stories	4.394	0.0007
				610284	3.142	0.0146
				Tran CATCODE	3.701	0.0195
	5-8	123	<.0001		-3.390	<.0001
				2 Stories	2.349	0.0019
				>2 Stories	4.083	<.0001
				610121	3.390	0.0268
	9-18	123	<.0001		-4.358	<.0001
				>2 Stories	4.196	0.0025
				<=9000	2.312	0.0103
				610675	3.867	0.0035
				5-8 yrs Comm	2.210	0.0195
Electrical	1-6	123	<.0001		-4.394	<.0001
				2 Stories	2.836	0.0134
				>2 Stories	6.004	<.0001
				610284	3.142	0.0146
				Tran CATCODE	3.701	0.0195
	7-18	123	0.0005		-2.565	<.0001
				>2 Stories	3.258	0.0006
				610243	1.553	0.0272
				610675	2.565	0.0169
HVAC	1-7	123	0.0034		-2.669	<.0001
				>2 Stories	2.669	0.0032
				610284	1.976	0.0145
	8-18	123	<.0001		-1.442	0.0047
				1 Story	-2.517	0.0003
				<=9000	1.823	0.0112
				610121	3.960	0.012
				1-7 yrs HVAC	1.938	0.0145
Plumbing	1-7	123	0.0002		-2.829	<.0001
				>2 Stories	3.306	0.0007
				610249	1.887	0.015
	8-18	123	0.0116		-2.370	<.0001
				>2 Stories	2.370	0.0071

Table 15: Addition and Modification Probability Formulas

System	Year Group	Probability Formulas
Additions	1-18	=EXP(-2.11+2.11*(>2 Stories)+2.11*(HQ Base Lvl))/(1+EXP(-2.11+2.11*(>2 Stories)+2.11*(HQ Base Lvl)))
Comm	1-4	=EXP(-4.394+3.353*(2 Stories)+4.394*(>2 Stories)+3.142*(610284)+3.701*(Tran CATCODE))/(1+EXP(-4.394+3.353*(2 Stories)+4.394*(>2 Stories)+3.142*(610284)+3.701*(Tran CATCODE)))
	5-8	=EXP(-3.39+2.349*(2 Stories)+4.083*(>2 Stories)+3.39*(610121))/(1+EXP(-3.39+2.349*(2 Stories)+4.083*(>2 Stories)+3.39*(610121)))
	9-18	=EXP(-4.358+4.196*(>2 Stories)+2.312*(<=9000)+3.867*(610675)+2.21*(5-8 yrs Comm))/(1+EXP(-4.358+4.196*(>2 Stories)+2.312*(<=9000)+3.867*(610675)+2.21*(5-8 yrs Comm)))
Electrical	1-6	=EXP(-4.394+2.836*(2 Stories)+6.004*(>2 Stories)+3.142*(610284)+3.701*(Tran CATCODE))/(1+EXP(-4.394+2.836*(2 Stories)+6.004*(>2 Stories)+3.142*(610284)+3.701*(Tran CATCODE)))
	7-18	=EXP(-2.565+3.258*(>2 Stories)+1.553*(610243)+2.565*(610675))/(1+EXP(-2.565+3.258*(>2 Stories)+1.553*(610243)+2.565*(610675)))
HVAC	1-7	=EXP(-2.669+2.669*(>2 Stories)+1.976*(610284))/(1+EXP(-2.669+2.669*(>2 Stories)+1.976*(610284)))
	8-18	=EXP(-1.442+-2.517*(1 Story)+1.823*(<=9000)+3.96*(610121)+1.938*(1-7 yrs HVAC))/(1+EXP(-1.442+-2.517*(1 Story)+1.823*(<=9000)+3.96*(610121)+1.938*(1-7 yrs HVAC)))
Plumbing	1-7	=EXP(-2.829+3.306*(>2 Stories)+1.887*(610249))/(1+EXP(-2.829+3.306*(>2 Stories)+1.887*(610249)))
	8-18	=EXP(-2.37+2.37*(>2 Stories))/(1+EXP(-2.37+2.37*(>2 Stories)))

From the logistic regression, ten out of twenty-eight CATCODEs were found to influence the probability of an addition or modification occurring. Table 16 shows the ten influential CATCODEs and the groups they belong to (United States Air Force Civil Engineers, 2012). Since the remaining eighteen CATCODEs have the same probabilities for all additions and modifications, they were combined and are discussed together.

Table 16: Influence CATCODE (United States Air Force Civil Engineers, 2012)

CATCODE Group	CATCODE	Description
NA	610243	Headquarters, Group
	610249	Wing Headquarters
	610675	Logistics Facility Depot Operations
HQ	610282	Headquarters Air Force
	610284	Headquarters Major Command
HQ Base Level	610281	Headquarters Center
	610287	Headquarters Specified
Transportation	610121	Vehicle Operations Facilities
	610142	Cargo Movement/Personal Property/Small Air Terminal and Passenger Movement Facilities
	610711	Data Processing Installation

The logistic regression cannot be used to determine the specific year an addition or modification occurred, to do this the actual occurrence percentages from the 123 sample facilities were used. Appendix D: Facility Sample Modification and Addition Occurrence Percentages contains the percentages from the sample facilities. These percentages were used in combination with a random uniform number from zero to one. For example, if the simulation predicts that a communication modification occurred between years one and four, a random number would be generated and if it was less than

0.217 then the modification would occur in year one, if the random number is between 0.217 and 0.483 then modification would occur in year two, if the random number is between 0.483 and 0.724 then modification would occur in year three, otherwise the modification would occur in year four. Through the logistic regression formulas and the sample occurrence percentages, modification and additions were predicted for each year in 18 year facility life-cycle.

The final step in determining facility demands is to determine the size of a modification and addition. One problem encountered in this step is that an average of only thirty-five percent of facility modification sizes are recorded in ACES-PM. In addition, twenty-eight percent of the thirty-five sizes had recorded sizes of one square foot. An investigation showed that modifications with small recorded sizes are often place holders to represent when a project worked on a particular system. These place holders are not an accurate representation of the project size. Figure 8 shows the distribution of electrical modification sizes. With a majority of size data unknown for modifications and small size numbers being used as place holders instead of modification sizes, sizes under 5 sq-ft were removed and sizes were converted into percentage of the facility size that was modified, then the median and means shown in Table 17 was used as a “low” and “high” modification size. In the simulation, both the mean and median modification sizes were used to generator two separate facility modification costs. As such, two standard designs were evaluated: 1) A median standard design with modification cost estimates from the median size percentages (a “low” modification size), and 2) a mean standard design with modification cost estimates from the mean size percentages (a “high” modification size). The distributions of communication, HVAC, and plumbing system modification sizes all were very similar to the electrical modification distribution shown in Figure 8 with only several sizes between 20 and 100 percent. Therefore, the median and means were used for each system modification size.

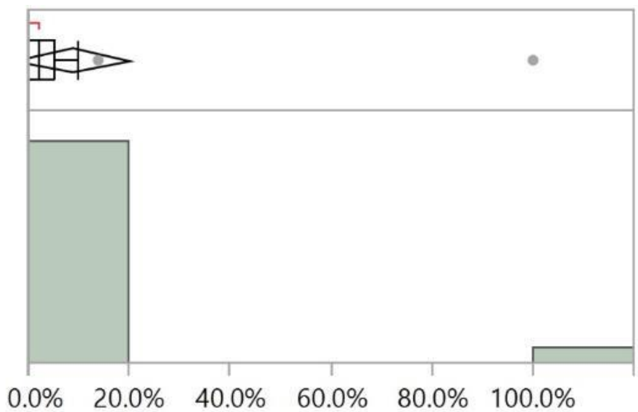


Figure 8: Distribution of Electrical Modification Size

Table 17: Averages of Sample Modification Sizes

	Median	Mean
Plumbing % Change	0.05	0.151
Communication % Change	0.105	0.218
Electrical % Change	0.125	0.222
HVAC % Change	0.05	0.22

The size information for additions was more complete with forty-one percent of addition sizes unknown and no sizes less than 150 sq-ft. Therefore, a Weibull distribution was fitted to the data in order for the MCS to gain the capability to predict the size of an addition. Figure 9 shows the Weibull distribution fitted to distribution of addition sizes that occurred across the 184 sample facilities. Table 19 shows the results of the Cramer-von goodness-of-fit test in the p-value column. The p-value of the Cramer-von test was greater than the alpha 0.1, therefore the fitted Weibull distribution passed and was used in the MCS.

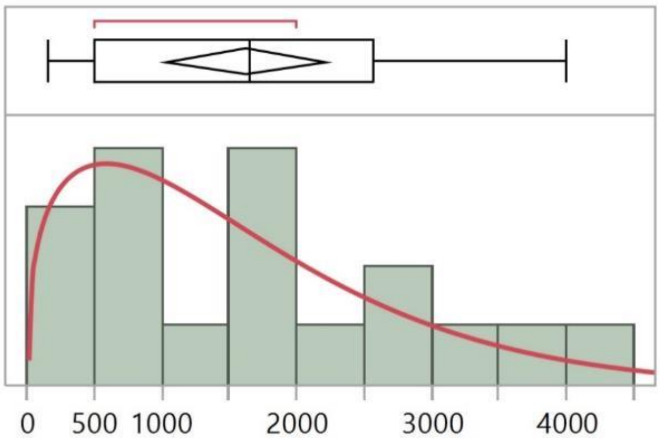


Figure 9: Addition Size Weibull Distribution Fit

Table 18: Weibull Distribution Goodness-of-Fit Test

System	Year Group	N	Fit Test p-value	Parameters Scale, α	Shape, β
Addition Size	**1-18**	123	0.25	1742.527	1.306

The goal of this step was to gain the capability of predicting facility demands for Air Force administrative facilities. The logistic regression formulas provide the capability of predicting the occurrence of modifications or addition in a fixed year group. Combined with modification and additions occurrence percentages from the 123 sample facilities, the specific year a modification or addition is predicted to occur, can be determined. Lastly, by using the median and mean of previous modifications that the 123 sample facilities experienced, and the Weibull distribution, the size of the predicted modifications and additions can be determined. Therefore, facility demands can be predicted across an eighteen year period using only the facility characteristics of size, number of stories, and CATCODE.

LCC Cost Estimation

Generating Cost Estimates

Before starting the construction cost estimation process, the flexible and robust facility design sizes were determined. The average flexible and average robust design sizes were calculated by taking the standard facility size, which is an input to the simulation, and adding that number to the mean of all the addition sizes that the 184 sample facilities (123 for sample facilities set and 61 for the validation facilities set) experienced in their service life. Then the large flexible and large robust design sizes were calculated by taking the average flexible and robust design sizes and adding one standard deviation of all the addition sizes that the 184 sample facilities experienced in their service life. Table 19 shows both the mean and the mean plus one standard deviation from the facility sample.

Table 19: Facility Design Size

Sample Facility Mean and Standard Deviation		
Average Design Size	**Mean Increase**	36.11%
Large Design Size	**Mean + Std Dev Increase**	59.96%

Using the facility size, number of stories, and CATCODE from the sample facilities, cost estimates were derived from PACES for each sample facility. These cost estimates were used to represent standard designs. Then robust average cost estimates were generated using the same input except the facility size was increased 36.11 percent. Large robust design cost estimates were collected using the same inputs as standard design except for the facility size was increased by 59.96 percent. Next a PACES cost report was used generate cost estimates for flexible average and large designs for each of the 184 sample facilities. Standard, average robust, and large robust designs were combined to generate cost estimates for flexible designs that are built at the standard design size but have the capability to expand to the robust design sizes. The PACES cost estimates for each facility sample are shown in Appendix E: PACES Facility Design Initial Construction Cost Estimates.

The PACES cost estimates for standard design additions were calculated in the same manner as the initial cost estimates for each of the 32 sample facilities that experienced an addition. Then a PACES level-2 cost report was used to generate the cost of additions that flexible designs experiences. The 32 addition cost estimates for both standard and flexible designs are shown in Appendix F: PACES Addition Costs Estimates.

Using the medians and means shown in Table 17, in combination with the sample facilities data already in PACES from construction cost estimation process, cost estimates were generated for each modifications the 184 sample facilities experienced. Table 20 shows the number of cost estimates generated for each system and the cost estimates for each sample are located in Appendix G: PACES Modification Costs Estimates.

Table 20: Number of Modification Cost Estimates

System	Size	Count
HVAC	Median	41
	Mean	41
Comm	Median	50
	Mean	50
Plumbing	Median	38
	Mean	38
Electric	Median	48
	Mean	48

Operational cost estimates were generated in the software CostLab® using the facility size, number of stories, and the year placed in service for each of 184 facility samples. Next, a CostLab® average summary report provided the average operating cost of each sample facility for 2015 through 2024. Finally, each of the five average facilities costs were aligned by operational year. The sample facilities ranged from 1 year old to 18 years old and cost estimates were collected standard, average, and large facilities sizes. There were sufficient cost estimates to perform a linear regression on each of the operational cost for every year for the 18-year evaluation period.

Estimating Facility Costs

To estimate the initial construction, addition, modification, and operational costs of each facility, linear regression was used to fit first or second polynomials to the plot of the LCC estimates by facility size. Each line and polynomial fit had to have an overall p-value of less than the 0.1 alpha and all factors must also have p-values less than the 0.1 alpha. In addition, Cook's distance values were analyzed to ensure all values were below one. If the line or polynomials were not statistically significant or did not pass Cook's distance standards, the cost estimation data was broken into two groups and new lines or polynomial were fitted to each group.

Each linear regression was statistically significant, but the linear regressions often produced high Cook's distance values when considered as a single group. As a result, additions and HVAC modifications were broken up into small groups. Additionally, one out of thirty-two communication costs estimates was excluded because of a high Cook's distances value.

For addition cost estimates of both standard and flexible designs, cost estimates were broken down into small groups in order to produce Cook's distance values less than one. For standard and flexible designs, additions were separated into three groups: addition size less than 2,000 sq-ft and one story, addition size less than 2,000 sq-ft and more than one story, and addition size greater than 2,000 sq-ft. By fitting a polynomial to each of the addition groups, the overall Cook's distance values were all less than one and the adjust R^2 values were decreased. The lower Cook's distance values means that the polynomials were less influenced by individual cost estimates and provide more accurate estimates of the actual cost. In addition, the higher adjusted R^2 value means that more variance in the polynomial and the cost estimate is explained by the size of the facility.

HVAC modification estimates were handled in a similar manner. Two groups were created for both median and mean cost estimates: facilities with one story and facility with more than one story. With these two HVAC facility groups results were the same as with the addition groupings. All Cook's distance values were below one and each group experienced an increase in adjusted R^2 values.

The linear regressions for each of eighteen operational year cost estimates proved to be the most challenging task in the LCC estimation. Due to the limitations of not having historic operational costs for each facility, and the CostLab parametric cost estimating software not being able to estimate historic operational costs and only having the ability to provide five year averages. The facility age was used in combination with the five-year cost estimate to provide cost samples for each operational year. For example, a five year old facility provided cost estimates for operational years six through ten. The results were that the first two operational years had less than thirty facility cost estimates since only a few of the facility samples were less than two years old, while later operational years had much larger samples sizes. The first operational year had nine cost estimates and the second year had eighteen. The low samples size in early operational years may cause inaccuracies in the early LCC estimates. However, all operational year cost estimation formulas were similar and produced nearly identical cost estimates regardless of sample size. In addition triangular distributions are able to capture some of the inaccuracy or uncertainty involved with each of the operational year estimates. However, by breaking the majority of operational years, that that had large sample sizes, into two size group split at 9,000 sq-ft, all Cook's distance values were less than one and the minimum adjusted R^2 recorded was 0.9327.

All the polynomials were significantly accurate to the cost estimates. As Appendix H: LCC Distribution Fit Results shows all the p-values of the F-test and t-test results are well below the alpha and the lowest record adjust R^2 is 0.9327. In addition, Appendix I: Cook's Distance Results shows that all Cook's distances values are below one. Therefore, the polynomial formulas shown in Appendix J: Cost Estimation Formulas are not overly influenced by any cost estimate, that facility size explains a minimum of 93.27 percent of the variance in the cost estimates, and the results of the p-values show that the polynomial is a statistically significant representative of the cost estimates.

Verification and Validation of Simulation Inputs

First, verification and validation was performed on the logistic regression facility demand prediction formulas and the linear regression LCC prediction formulas using both the 123 sample facilities that were used to generate the predicting formulas and the 61 addition sample facilities. The results of the 123 and the 61 sample facilities were compared to ensure the simulation accurately predicts facility modification, additions, and LCC. In addition, the percent error that was found during the verification and validation of the LCC prediction formulas, was used to construct triangular distributions that represent the uncertainty in each of the LCC estimates.

Table 21 shows the verification and validation results for the ten logistic regression formulas that were used to predict whether an addition or modification occurred for each of the 123 sample facilities that were used to generate the simulation.

The green table cells represent the number of correct predictions and the red table cells show the number of incorrect predictions. The overall accuracy of each formula was calculated by taking total number of correct predictions and dividing by 123. The mean accuracy is 89.18 percent with a minimum accuracy of 85.32 percent. These accuracies mean that the formulas correctly predicted the occurrence of modifications and additions for 123 facilities more than 85.32 percent of the time.

Table 21: Demand Prediction 123 Sample Facilities Verification and Validation

		Est No Mod	Est Mod	Correct/Total Actual Rows	Correct/Total overall
1-19 Yrs Addition	Act No Mod	99	6	0.9429	0.8537
	Act Mod	12	6	0.3333	
1-7 yrs HVAC	Act No Mod	107	3	0.9727	0.8943
	Act Mod	10	3	0.2308	
8-19 yrs HVAC	Act No Mod	102	5	0.9533	0.8699
	Act Mod	11	5	0.3125	
1-4 yrs Comm	Act No Mod	107	3	0.9727	0.8532
	Act Mod	10	3	0.2308	
5-8 yrs Comm	Act No Mod	107	2	0.9817	0.9024
	Act Mod	10	4	0.2857	
9-19 yrs Comm	Act No Mod	108	2	0.9818	0.9350
	Act Mod	6	7	0.5385	
1-6 yrs Electric	Act No Mod	109	1	0.9909	0.9268
	Act Mod	8	5	0.3846	
7-19 yrs Electric	Act No Mod	102	4	0.9623	0.8780
	Act Mod	11	6	0.3529	
1-7 yrs Plumbing	Act No Mod	108	2	0.9818	0.9106
	Act Mod	9	4	0.3077	
8-19 yrs Plumbing	Act No Mod	107	3	0.9727	0.8943
	Act Mod	10	3	0.2308	

However, the prediction formulas were created using the 123 sample facilities. Therefore, the true accuracy of the formulas was evaluated based on the results of the 61 sample facilities.

Table 22 shows the verification and validation results of the 61 additional sample facilities. The mean accuracy is 80.03 percent with a minimum accuracy of 77.05 percent. These accuracies mean that the formulas correctly predicted the occurrence of modifications and additions for additional 61 facilities more than 77.05 percent of the time. While, the formulas were not as accurate at predicting modifications and additions of the additional 61 sample facilities, the results formulas were still more than 77.05 accurate overall. In addition, future research can improve the accuracy of the formula by including more inputs into the logistic regression process. Table 23 shows a comparison between the 123 sample facilities and the addition 61 facilities.

Table 22: Demand Prediction 61 Sample Facilities Verification and Validation

		Est No Mod	Est Mod	Correct/Total Actual Rows	Correct/Total overall
1-19 Yrs Addition	Act No Mod	47	6	0.8868	0.8033
	Act Mod	6	2	0.2500	
1-7 yrs HVAC	Act No Mod	45	3	0.9375	0.7869
	Act Mod	10	3	0.2308	
8-19 yrs HVAC	Act No Mod	46	9	0.8364	0.8033
	Act Mod	3	3	0.5000	
1-4 yrs Comm	Act No Mod	46	6	0.8846	0.8532
	Act Mod	7	2	0.2222	
5-8 yrs Comm	Act No Mod	49	5	0.9074	0.8197
	Act Mod	6	1	0.1429	
9-19 yrs Comm	Act No Mod	53	2	0.9636	0.9016
	Act Mod	4	2	0.3333	
1-6 yrs Electric	Act No Mod	41	2	0.9535	0.7705
	Act Mod	12	6	0.3333	
7-19 yrs Electric	Act No Mod	48	5	0.9057	0.8033
	Act Mod	7	1	0.1250	
1-7 yrs Plumbing	Act No Mod	44	2	0.9565	0.7869
	Act Mod	11	4	0.2667	
8-19 yrs Plumbing	Act No Mod	53	5	0.9138	0.8852
	Act Mod	2	1	0.3333	

Table 23: Summary Statistics of 123 and 61 Sample Facilities

	Sample Facilities	
	123	61
Mean	0.8918	0.8003
Std Dev	0.0283	0.0782
Max	0.9350	0.9143
Min	0.8532	0.7705

Another factor that must be considered in these verification and validation results is that Table 21 and

Table 22 show a large portion of the formula's accuracy is a result of predicting that no addition or modification will occur. In predicting that an addition or modification does not occur, the formula was accurate at a minimum of 83.64 percent. Where as in predicting an addition or modification does occur the formula was only accurate a minimum of 12.50 percent. Since the LCC of standard designs benefit when no or minimal facility additions and modifications occur, the overall results of the LCC simulation will favor standard designs over flexible and robust designs. The accuracy of predicting the occurrence of additions and modification can be increased by adding more facility data that can be used to improve the accuracy of the logistic regression.

Next, the LCC cost estimation formulas were validated. The LCC cost estimation formulas were evaluated using the mean absolute percent error (MAPE) of the additional 61 sample facilities. The MAPE represents the average percent the cost estimate differed from the 61 sample facilities parametric cost estimates. Table 24 shows the verification and validation results of the initial construction, modification, and operational cost estimation formulas. The average MAPE between all of the formulas is 5.32 percent and the maximum is 8.12 percent. This maximum signifies that the mean of all the construction, modification, and operational cost estimates were less than 8.12 percent off from the parametric cost estimates for each of the 61 additional sample facilities. This means that the cost estimation formulas are within the 10 percent requirement and are an accurate representative of the mean of the parametric cost estimates.

Table 24: Facility Cost Estimation Verification and Validation

	Type	MAPE	MAPE Size<=4K	MAPE Size Between (4K & 9K)	MAPE Size Between (9K & 25K)	MAPE Size >25K
Construction Costs	**Standard**	6.67%	9.48%	8.14%	3.08%	2.85%
	Robust Average	5.91%	10.18%	6.87%	4.76%	2.90%
	Robust Large	6.07%	12.00%	7.04%	5.69%	2.62%
	Flexibility Average	5.71%	2.94%	2.28%	0.32%	1.15%
	Flexibility Large	5.87%	8.70%	5.77%	3.42%	3.25%
Modification Costs	**Median Comm**	2.95%	4.83%	4.00%	NA	2.36%
	Mean Comm	2.70%	5.70%	4.65%	NA	1.64%
	Median Electrical	8.12%	3.54%	8.15%	NA	9.64%
	Mean Electrical	5.65%	3.58%	5.97%	NA	6.20%
	Median HVAC	2.67%	1.99%	1.57%	NA	3.36%
	Mean HVAC	2.17%	1.85%	2.31%	NA	2.16%
	Median Plumbing	4.13%	0.75%	3.67%	NA	5.14%
	Mean Plumbing	2.29%	2.83%	2.59%	NA	2.00%
Operational Costs	**Op Year 1**	3.10%	2.69%	3.81%	2.28%	NA
	Op Year 2	5.06%	5.61%	5.03%	4.85%	2.27%
	Op Year 3	4.85%	2.54%	5.49%	6.46%	6.38%
	Op Year 4	5.54%	2.66%	3.39%	12.77%	3.68%
	Op Year 5	7.26%	2.38%	4.70%	16.41%	5.90%
	Op Year 6	7.12%	2.39%	4.53%	16.41%	5.90%
	Op Year 7	6.31%	2.29%	4.11%	12.87%	6.12%
	Op Year 8	5.88%	2.15%	11.51%	3.72%	6.28%
	Op Year 9	5.84%	2.01%	5.85%	11.06%	5.51%
	Op Year 10	5.19%	2.18%	5.28%	8.62%	5.26%
	Op Year 11	5.50%	2.17%	5.77%	9.56%	5.25%
	Op Year 12	6.06%	2.22%	8.18%	9.16%	5.28%
	Op Year 13	6.39%	2.57%	8.26%	8.94%	5.69%
	Op Year 14	5.90%	2.79%	8.06%	6.40%	5.80%
	Op Year 15	5.91%	2.55%	8.22%	7.04%	5.19%
	Op Year 16	6.07%	2.77%	8.11%	7.42%	5.45%
	Op Year 17	5.97%	3.17%	7.28%	7.45%	5.04%
	Op Year 18	6.05%	3.93%	6.85%	7.03%	5.51%

However, the overall MAPE does not represent the accuracy of the cost estimates for each of the different sizes of facilities. For example, the MAPE of small facilities may be very small and the MAPE of large facility may be very large. In this regard, the overall MAPE would not indicate that most of the accuracy comes from smaller facilities. Therefore, as Table 24 shows, the MAPE of the four facility size groups was calculated and the maximum MAPE for each of the size groups is 16.41 percent with an average of 5.27 percent. Most of the high MAPE values occurred in the operational cost estimates for facilities between 9,000 and 20,000 sq-ft. For this research all MAPE values had to be less than twenty percent to ensure the estimates were an accurate representation of the LCC for each facility design in order to adequately answer the research questions. The risks associated with the accuracy of the cost estimates is mitigated since the operational costs are included in all the facility designs and since triangular distributions were used to represent the possibility of inaccurate estimates in the simulation. The MAPE values can be decreased in future research by creating smaller groups of facilities that have similar characteristics, such as number of stories or smaller facility size groups.

The overall MAPE values for facilities addition cost estimates were similar to the rest of the LCC cost estimates in Table 24. However, most facility additions were small in size and more dependent on the number of stories the existing facility had. Therefore, in addition to the overall MAPE values, the MAPE was calculated for three groups based on number of stories and addition size. As Table 25 shows, the MAPE values are similar to the MAPE values of other LCC cost estimates. Higher MAPE values were seen in facilities less than 2,000 sq-ft that have more than one story. These MAPE values can be decreased by separating facilities into additional groups such as facility sizes less than 2,000 sq-ft and two stories. Regardless, all MAPE values are well below the twenty percent maximum criteria for this research.

Table 25: Addition Cost Estimation Verification and Validation

Type	MAPE	MAPE Size <= 2000 & 1 Story	MAPE Size <= 2000 & >1 Story	MAPE Size >2000
Standard Addition Cost	8.07%	0.61%	11.71%	9.12%
Flexible Addition Cost	9.73%	1.73%	13.04%	11.60%

The last phase of the verification and validation step was calculating triangular distributions for each LCC estimation formulas. The triangular distributions were used in the simulation to represent the uncertainty or potential inaccuracies of the LCC estimates. A triangular distribution requires three inputs: maximum, minimum, and mean. In order for the triangular distribution to represent the uncertainty or inaccuracy of the cost estimates, the percent error (PE) of each cost estimate for the 185 sample facilities was used. The percent error provides the percent that the formula cost estimate differed from the parametric cost estimate. By taking the PE and adding one a number was created and it was used to adjust the formula cost estimate. For example, if the PE of a cost estimate is -5% than multiplying the cost estimate by 95% adjusts the cost estimates and removes the PE. However, the PE is only removed for one cost estimate. In order to represent the PE of the cost estimates in the simulation, a range must be used. Using the maximum and the minimum values of one plus the PE for each of the cost estimation formulas, the inaccuracy of the cost estimates was considered as part of the model. The triangular distribution allows the generation of numbers between the maximum and minimum values and uses the mean to increase the likelihood of generating numbers close to the average. Figure 10 shows the triangular distribution for construction cost adjustment of standard designs. Table 26 contains the triangular distribution input for each of the cost estimation formulas.

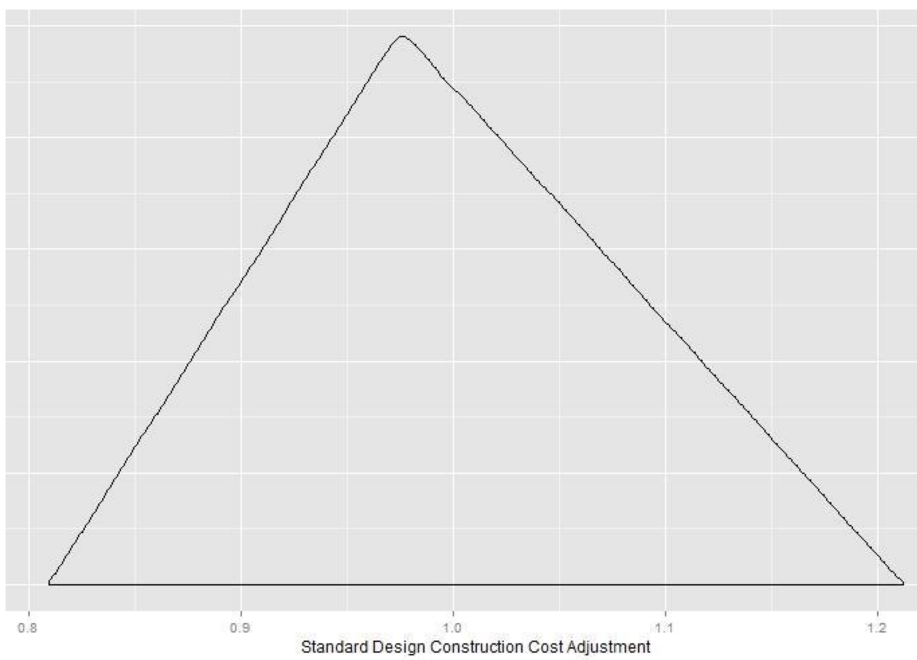


Figure 10: Standard Design Construction Cost Triangular Distribution

Table 26: Triangular Distribution Inputs

Type		Max(1+PE)	Min(1+PE)	Mean(1+PE)
Construction Costs	**Standard**	1.2123	0.8094	0.9755
	Robust Average	1.1791	0.8202	0.9779
	Robust Large	1.1769	0.7757	0.9714
	Flexibility Average	1.1822	0.8527	0.9819
	Flexibility Large	1.1816	0.8261	0.9762
Modification Costs	**Median Comm**	1.0687	0.9503	1.0072
	Mean Comm	1.1275	0.7896	1.0104
	Median Electrical	1.2734	0.7933	1.0047
	Mean Electrical	1.1275	0.7896	1.0210
	Median HVAC	1.1216	0.9474	1.0105
	Mean HVAC	1.0755	0.9448	1.0067
	Median Plumbing	1.0829	0.9052	1.0059
	Mean Plumbing	1.0652	0.9285	1.0004
Addition Costs	**Standard Addition**	1.2315	0.8991	1.0350
	Flexible Addition	1.2472	0.8579	1.0490
Operational Costs	**Op Year 1**	1.0385	0.9451	1.0043
	Op Year 2	1.1070	0.8889	0.9869
	Op Year 3	1.1085	0.9128	0.9909
	Op Year 4	1.1377	0.7222	0.9816
	Op Year 5	1.1317	0.6417	0.9724
	Op Year 6	1.1317	0.6417	0.9732
	Op Year 7	1.1325	0.6870	0.9783
	Op Year 8	1.1208	0.7167	0.9790
	Op Year 9	1.1692	0.7144	0.9799
	Op Year 10	1.1704	0.7493	0.9859
	Op Year 11	1.1684	0.7268	0.9853
	Op Year 12	1.1630	0.7002	0.9848
	Op Year 13	1.1522	0.6989	0.9844
	Op Year 14	1.1439	0.8485	0.9947
	Op Year 15	1.1415	0.8683	1.0010
	Op Year 16	1.1776	0.8545	1.0014
	Op Year 17	1.1761	0.7947	0.9994
	Op Year 18	1.1758	0.4860	0.9964

Facility Lifecycle Simulation

The facility lifecycle simulation was created using RStudio® and the programming code is located in Appendix K: RStudio® Facility LCC Simulation Code. The simulation requires three facility characteristic as inputs: CATCODE, size, and the number of stories. The simulation was created from and for administrative facilities and therefore the first three digits of the CATCODE must be "610" in order for simulation results to be accurate. The MCS can generate LCC for any facility size, but the size input must be the total floor area required for a standard design and the units must be sq-ft. The number of stories input can be any integer value.

For one set of facility inputs the simulation generates 60,000 potential eighteen year LCC estimates. The simulation provides 10,000 LCC estimates for six potential facilities designs. The six facility designs are as follows:

- Standard design with median modification costs (Standard Design, Small Modifications)
- Standard design with mean modification costs (Standard Design, large Modifications)
- Flexible design with 36% size growth capability (Flexible Design, Average Capacity)
- Flexible design with 60% size growth capability (Flexible Design, Large Capacity)
- Robust design, built 36% larger then requirement (Robust Design, Average Size Increase)

- Robust design, built 60% larger then requirement (Robust Design, Large Size Increase)

LCC are generated for each of the six facility deigns using through

.

$$LCC_S = C_S + \sum O + \sum MS + \sum A_S \qquad (\qquad)$$

$$LCC_S = C_S + \sum O + \sum ML + \sum A_S \qquad (\qquad)$$

$$LCC_{FA} = C_{FA} + \sum O + \sum A_{FA} \qquad (\qquad)$$

$$LCC_{FL} = C_{FL} + \sum O + \sum A_{FL} \qquad (\qquad)$$

$$LCC_{RA} = C_{RA} + \sum O_{RA} \qquad (\qquad)$$

$$LCC_{RL} = C_{RL} + \sum O_{RL} \qquad (\qquad)$$

where

$LCC_S = Lifecyle\ Cost$
$C_x = Initial\ Cosntruction\ Cost$
$O_x = Operational\ Cost$
$MS = Small\ Modificaiton\ Cost$
$ML = Large\ Modificaiton\ Cost$
$A_S = Addition\ Cost$
$_S = Standard\ Facility\ Design$
$_{FA}$ = Flexible Design, Average Capacity
$_{FL}$ = Flexible Design, Large Capacity
$_{RA}$ = Robust Design, Average Size Increase
$_{RL}$ = Robust Design, Large Size Increase

The simulation generates cost estimates for each operational year across eighteen years. Before the first year, the initial construction costs are calculated for each design using the simulation inputs, the facilities size increases of thirty-six percent and sixty percent, and the initial construction cost estimation formulas shown in Table 27.

Table 27: Construction Cost Estimation Formulas

Design	Size	Cost Estimation Formulas
Standard	All	=793066.85+204.497*(Facility Size)
Flexible	Average	=748729.11+267.127*(Facility Size)
	Large	=781230.04+302.581*(Facility Size)
Robust	Average	=800109.8+205.695*(Avg Facility Size)
	Large	=860659.69+202.424*(Large Facility Size)

Next, the simulation generated costs for each potential operational year. At the beginning of each year a random number generator and the logistic regression probability formulas are used to determine if a modification is predicted to occur in that year. If a modification is predicted then both mean and median cost estimates are generated for standard designs. Then operational costs for the year are generated for each of the six facility designs based on the facility size. At the end of the year a random number generator and the probability formulas are used to predict if an addition will occur during the year. If addition did occur, a random number along the Weibull distribution is used to determine the size of the addition. Then the costs of the addition are generated for both flexible and standard designs. Robust designs and flexible designs have the same addition costs as standard designs when the size of the facility grows beyond the initial facility increases of thirty and sixty percent. The simulation will then add the addition size to the facility size for reminder of the eighteen year lifecycle. The process for generating costs for the operational year is then repeated for operational years two through eighteen. After the costs for construction and each operational year were generated the cost estimates were added together for each of the six designs. Table 28 contains the results of one LCC sample. Then the facility size, CATCODE, number of stories, and the six LCC for each design are recorded and the simulation repeats the entire processes again for total of 10,000 LCC samples.

Table 28: Example Output - Standard Median Design Eighteen Year LCC

	Size	CATCODE	Number of Stories	Design	Total Cost
Model Inputs	2000	610281	1	Standard Median	$4,504,969.50
Year	**Construction Cost**	**Operational Cost**	**Median Modification Cost**	**Addition Cost**	**Addition Size**
0	$1,121,954.56	$0.00	$0.00	$0.00	0
1	$0.00	$45,106.45	$0.00	$0.00	0
2	$0.00	$45,556.93	$0.00	$0.00	0
3	$0.00	$43,075.07	$821,068.43	$0.00	0
4	$0.00	$45,323.74	$0.00	$0.00	0
5	$0.00	$42,639.68	$0.00	$0.00	0
6	$0.00	$44,414.88	$164,906.98	$0.00	0
7	$0.00	$39,850.05	$0.00	$0.00	0
8	$0.00	$42,725.11	$0.00	$0.00	0
9	$0.00	$45,593.94	$0.00	$0.00	0
10	$0.00	$37,952.21	$463,045.93	$0.00	0
11	$0.00	$46,955.19	$0.00	$0.00	0
12	$0.00	$44,053.41	$239,564.50	$0.00	0
13	$0.00	$35,222.04	$0.00	$847,562.22	936
14	$0.00	$58,253.16	$0.00	$0.00	0
15	$0.00	$60,303.64	$0.00	$0.00	0
16	$0.00	$64,423.61	$0.00	$0.00	0
17	$0.00	$57,485.20	$0.00	$0.00	0
18	$0.00	$47,932.60	$0.00	$0.00	0

Analysis

The MCS was used to answer both research question by varying the inputs and analyzing the LCC results of each design. The simulation has three different inputs: CATCODE, size, and number of stories. The CATCODE input, as previously discussed, has eleven different combinations that produce significantly different results. The facility size and number of stories inputs both have three different combinations that produce significantly different results. The three groups are significantly different because each size and number of stories group, changes the probability of modifications or additions occurring. Table 29 lists all the significant simulation inputs, which were determined through the logistic regression results.

Table 29: Significant Simulation Inputs

Input Types	Simulation Input
CATCODE	610121
	610142
	610243
	610249
	610281
	610282
	610284
	610287
	610675
	610711
	All Other 610 CATCODE
Size	Size<=4000 sq-ft
	4000<Size<=9000 sq-ft
	9000<Size
Number of Stories	1
	2
	>2

Since each combination of these inputs produced unique results, the simulation was ran all of the 99 different combinations. Rather than the researcher manually running the simulation for each combination, the simulation was programmed to cycle through each of the inputs and record all 60,000 LCC along with each set of inputs and the design type. The results were 5.94 million LCC estimates; 10,000 LCC samples for six facility designs provided for 99 different inputs.

All of the facility design LCC were combined into a single table and ANOVA was performed on the LCC. However, due to the 5.94 million LCC estimates the ANOVA software treated the sample as a population and in a population any difference is treated as significant. Since there is a difference between almost any cost estimate, the ANOVA showed that all simulation inputs and interactions between inputs were significant, even though this may not be true. For example if the LCC estimate between two designs is different by 100 dollars the ANOVA say that the difference is significant. However, a 100 dollar difference on a million dollar cost estimate may be statistically significant, it is not practically significant. Therefore an ANOVA could not be used to answer the research questions.

Instead box-plots were created to visually show how each simulation input affects the LCC of each of the six designs. Figure 11 shows each of the six different values the box plot communicates. Since the box-plot show the circumstances in which each design results in the LCC, conclusions were drawn and discussed in the next chapter that answers the second research question. Figure 12 contains a box-plot for each of the six facility designs and each of the CATCODEs. However, the LCC for each CATCODE contain varying facility sizes and number of stories. For example, a 1,000 square feet (sq-ft) facility would result in a much different LCC than a 100,000 sq-ft facility. Therefore, the results of all of the designs were normalized at the LCC level, which enables the comparison of the performance of each design regardless of the difference in LCC due to differing facility characteristics.. Therefore, each of the 10,000 LCC estimates were normalize and converted into the percent of total cost of all facility designs within a single potential life-cycle. This total percentage allows the comparison of each facility regardless of cost. Figure 13 shows the LCC box-plots of each of the six designs with simulation inputs of number of stories and size. The combination of the facility size and number of stories and the CATCODE box-plots provides a method for answering the first research question.

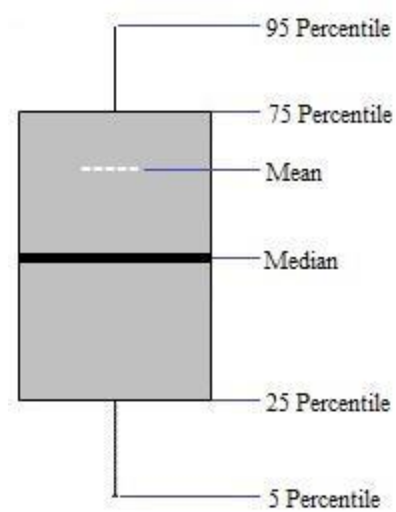


Figure 11: Box Plot Key

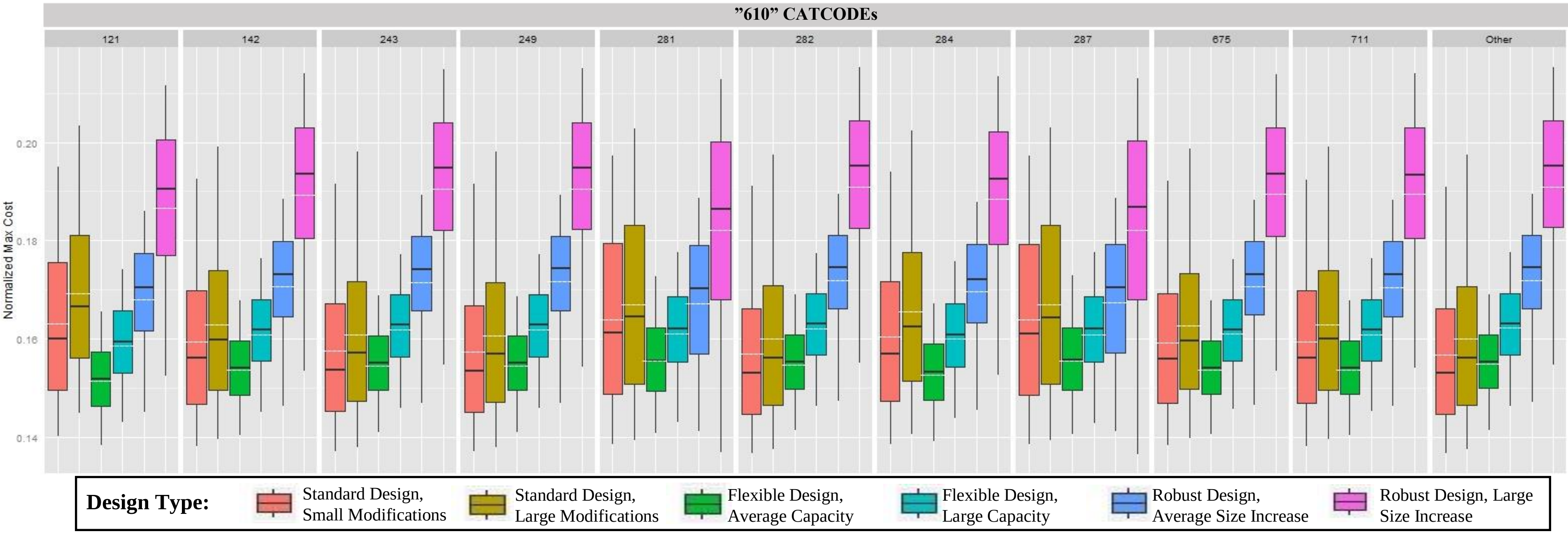


Figure 12: Results CATCODE Simulation Input

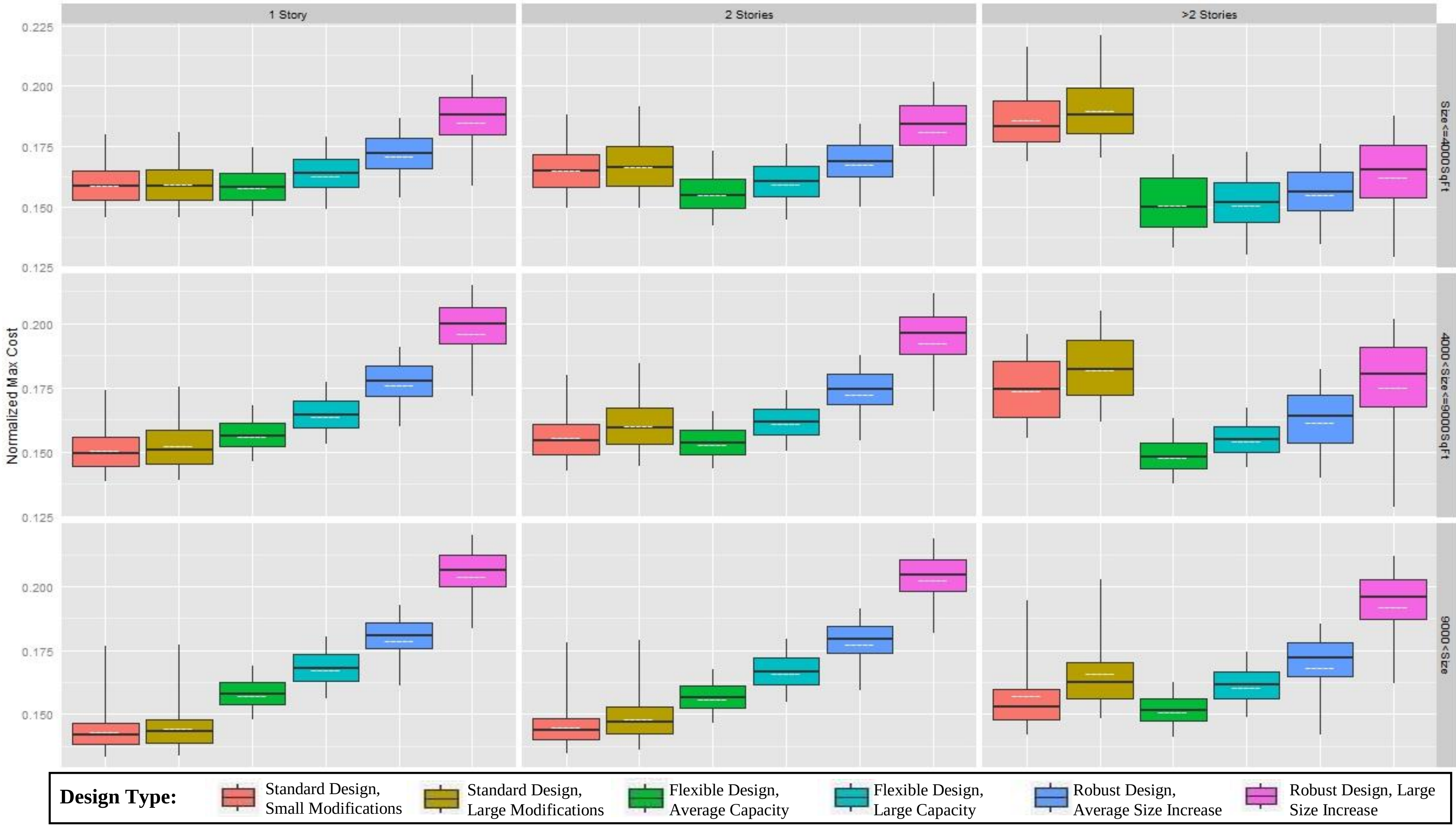


Figure 13: Results for Simulation Inputs Number of Stories and Facility Size

Due to the 5.94 million LCCs the simulation generated, an ANONA could not be used to answer the first research question. A box-plot of the overall LCC percentage was also used to answer the first research question. The box-plot in

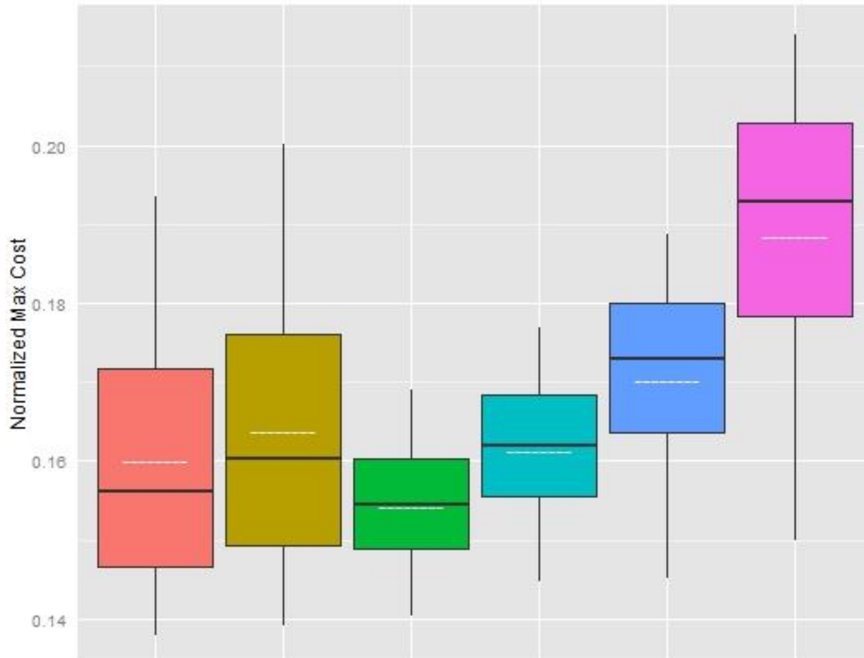


Figure 14 shows the LCC percentages of each design aggregating the 99 different combinations of CATCODE, facility size, and number of stories. The box-plot provides a visual representation of the how each facility design preformed over all 99 different facilities combination. However, the box-plot does not provide a clear understanding of how each facility design compares to another. Therefore, in addition to representing the LCC visually using a box-plot each design was ranked one through six based on the summary statistics for each of the 10 thousand potential facility lifecycles. The summary statistics used to rank each design were the mean, median, IQR, and standard deviation. Then the mean average rank for each design was recorded in a table for each of the summary statistics and an overall rank was generated by using the average rank of each design across all of the summary statistics. The rank results of each design LCC are displayed in Table 30.

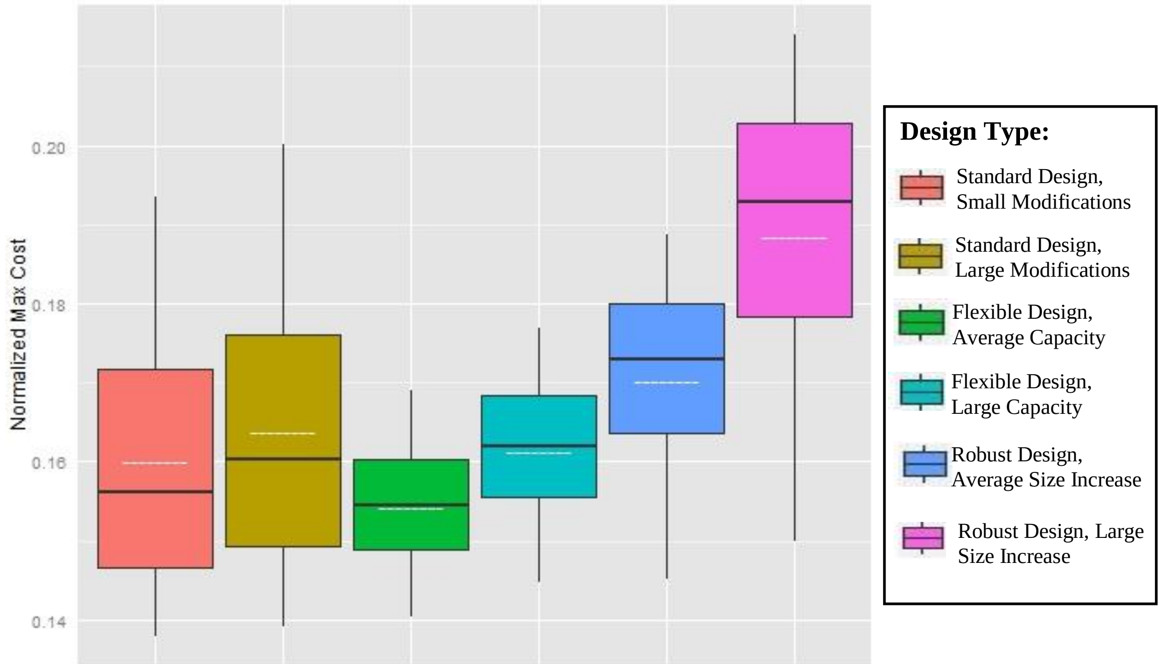


Figure 14: Overall LCC Percentage Results

Table 30: Summary of Ranked Facility Design Results

Design	Size	Means	Median	Std Dev	IQR	Overall
Standard	Median	2.4545	2.3030	3.9899	2.2727	2.7551
Standard	Mean	3.7879	3.5758	5.0505	3.8687	4.0707
Flexible	Average	1.9091	2.0303	1.0404	1.7677	1.6869
Flexible	Large	2.8081	2.8990	2.4343	3.9394	3.0202
Robust	Average	4.4040	4.4949	2.7980	3.4040	3.7753
Robust	Large	5.6364	5.6970	5.6869	5.7475	5.6919

V. Conclusions and Recommendations

Overview

The Air Force as a whole is focusing on addressing uncertainty and change with fewer resources. The status quo in the Air Force is to build two types of facilities: facilities with standard designs that do not consider future demands or facilties with robust designs that meet short term future demands through a larger initial facility size. The objective of this research was to determine if flexible facilities have the ability to meet changing demands at reduced LCC. From this research objective, two research questions were created that guided the research process:

- When comparing flexible, robust, and standard designs for an administrative facility, which alternative represents the greatest LCC savings to the Air Force?
- Under what facility characteristics do flexible, robust, and standard designs result in the lowest LCC?

To answer these two research questions a Monte Carlo simulation (MCS) was created to evaluate the LCC of two standard designs, two robust designs, and two flexible designs. The simulation generated 10,000 LCC estimates for each of the six designs and was run for each of the combinations of the simulation's three facility characteristics inputs. The results of all designs were normalized at the LCC level and displayed using box-plots. This chapter will use the box-plots and summary statistics of each facility design to answer the research questions, draw conclusions, and provide recommendations.

Assumptions

The research has four assumptions that may impact the LCC results of each design. First, keyword searches and quality checks were conducted on historic facility project documentation in order to determine the systems that were modified or if an addition occurred. A keyword search would often identify multiple system modification, however, the size of the modifications were not included. Therefore, an assumption was made that all system modifications had the same scope as the controlling project. For example a project might upgrade 20 percent of a facility and three systems were modified as part of the project. It would be assumed that each of the three systems were underwent an 20 percent modification when in reality each system may have only been a portion of the overall upgrade.

Second, while there are lots of different types of system modifications that can occur throughout the lifecycle of a facility, an assumption was made that only electrical, communication, HVAC, and plumbing systems would experience different costs depending on the facility design. Since both flexible and robust designs are initial constructed with larger electrical, communication, HVAC, and plumbing systems then these two types of design would not experience increase modification costs since they would already be capable of meeting the change in demand.

Third, the modifications and additions used to predicted future facility demands were all based on the sample facilities. Therefore, an assumption had to made that all three types of facility designs would experience close to the same facility demands. This assumption can be validated by collecting separate facility histories from standard, flexible, and robust facility designs.

Fourth, flexible designs requires a commitment to funding less expensive but more frequent modifications (de Neufville & Scholtes, 2011). Therefore, another assumption of this research is that any modification of flexible, robust, or standard designs to meet a new demand is fully funded.

Limitations

Limitations of the Design

To properly compare robust, flexible and standard designs, the limitations of each must be considered. The robust designs produce a larger facility. Therefore, as the example in Figure 15 shows, until the planned change in demand occurs at year 9 the robust design experiences increased annual operational costs A robust design preforms poorly under two situations that are not represented in the simulation. The first situation that affects LCC occurs if a facility does not experience an addition. Since, a robust design is built larger initial to support future additions, if the facitlity does not experience an addition the facility remains underutilized and has higher annual operational costs than standard or flexible facilities. The second situation occurs when a new or unpredicted demand materializes that the facility cannot meet. In this event, the robust facility incurs the costs of a modification, and provides little benefit over a standard design. The shortfalls of robust designs are that they often have high LCC and perform poorly with high levels of uncertainty. The simulation evaluates flexible designs that were able to grow by 36 percent and 60 percent larger than the original facility. If there is never a demand for the facility to grow, then there will be little return on the investment in the flexible design, and again there would be little cost advantage over a standard design. Therefore, flexible designs perform poorly when there is low uncertain in facility demands and when there are minimal predicted demand changes throughout the potential facility lifecycle. Standard designs are do not address future requires and preform well where flexible design perform poorly, low uncertain in facility demands and when there are minimal predicted demand changes throughout the potential facility lifecycle.

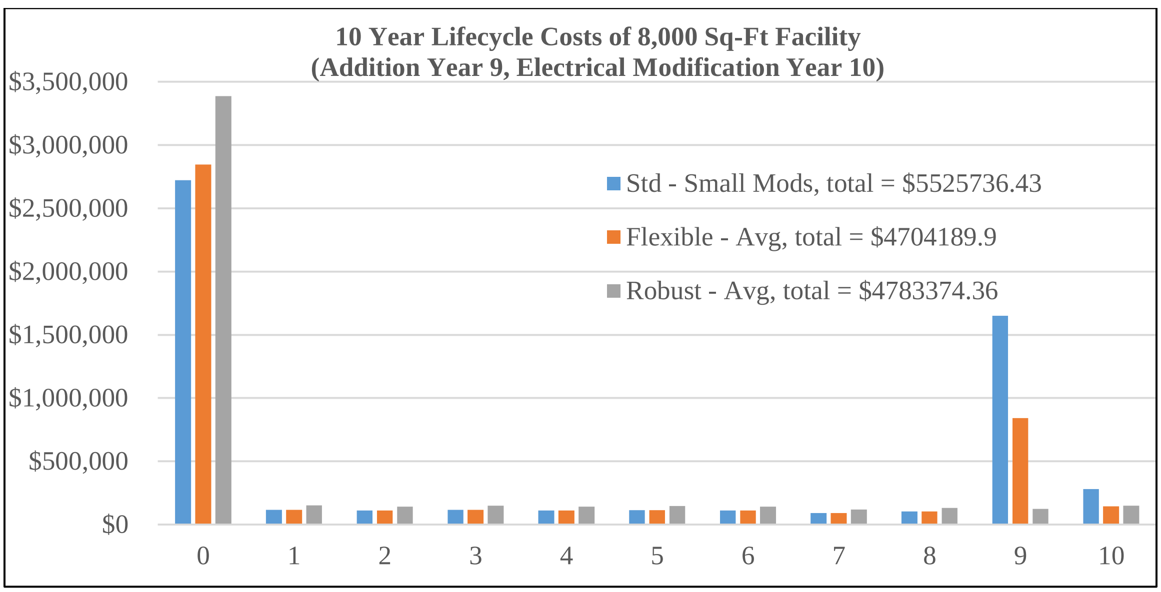


Figure 15: Life-Cycle Costs Facility Design Comparison

Depending on the number and scope of facility demand changes any of the three design alternatives may result in the lowest lifecycle cost. For example, if a facility experiences zero or few demand changes, then a standard design would result in the lowest LCC because it experiences the lowest initial cost and operational cost. If a facility experiences only one predicted change early in the facility life, then robust design may produce the lowest LCC. However, if multiple demand changes occur across the facility's life, then a flexible facility design may produce the lowest LCC. Therefore, it is important that the current design process has the capability to accurately predict facility demands in order to determine what type of facility design lends itself to the lowest cost to the Air Force.

Limitations of the simulation

The following five limitations may effect the LCC of the facility design: 1) only two flexible and robust facility designs are evaluated, 2) low accuracy at predicting the occurrence of modifications and addition, 3) modification and addition occurrence probabilities apply to periods instead of years, 4) 18-year LCC were evaluated and 5) only LCC were evaluated. This section describes how each limitation may affect the facility design LCCs.

First, the simulation evaluates two specific sizes of flexible and robust designs but the optimal facility size that results in the lowest LCC may change for each facility. For example, if an initial facility size was 2,000 sq-ft facility and experienced a 1,000 sq-ft addition, a flexible design with 50 percent growth capacity or a robust design that was constructed 50 percent larger may produce the lowest LCC. However, if the initial facility size was 200,000 sq-ft instead of 2,000 than the flexible design with 50 percent growth capacity and the robust design built 50 percent larger would not result in the optimal design in terms of lowest LCC. Therefore, the simulation can be improved by evaluating multiple facility design sizes and letting the lowest LCC result determine the flexible design growth capacity and the robust design size .

Second, the results in

Table 31 of the verification and validation show that most of the accuracy in predicting the occurrence of an addition or modification comes from predicted that an addition or modification does not occur. On average the simulation is only 27.4 percent accurate at predicting the occurrence of additions and modifications and 91.5 percent accurate at correctly predicting no additions or modifications occurring. This low accuracy means that simulation does not capture all of additions and modifications that will likely occur in the 18-year lifecycle. Since standard designs experience increased LCC for each occurrence of an addition or modification, the simulation may produce standard designs LCC that are less than what may actually occur. This limition can be improved in future research by collecting more sample facility data that will provide more potential logistic regressions factors that increase the accurate of the formulas.

Table 31: Demand Prediction 61 Sample Facilities Verification and Validation

		Est No Mod	Est Mod	Correct/Total Actual Rows	Correct/Total overall
1-19 Yrs Addition	Act No Mod	47	6	0.8868	0.8033
	Act Mod	6	2	0.2500	
1-7 yrs HVAC	Act No Mod	45	3	0.9375	0.7869
	Act Mod	10	3	0.2308	
8-19 yrs HVAC	Act No Mod	46	9	0.8364	0.8033
	Act Mod	3	3	0.5000	
1-4 yrs Comm	Act No Mod	46	6	0.8846	0.8532
	Act Mod	7	2	0.2222	
5-8 yrs Comm	Act No Mod	49	5	0.9074	0.8197
	Act Mod	6	1	0.1429	
9-19 yrs Comm	Act No Mod	53	2	0.9636	0.9016
	Act Mod	4	2	0.3333	
1-6 yrs Electric	Act No Mod	41	2	0.9535	0.7705
	Act Mod	12	6	0.3333	
7-19 yrs Electric	Act No Mod	48	5	0.9057	0.8033
	Act Mod	7	1	0.1250	
1-7 yrs Plumbing	Act No Mod	44	2	0.9565	0.7869
	Act Mod	11	4	0.2667	
8-19 yrs Plumbing	Act No Mod	53	5	0.9138	0.8852
	Act Mod	2	1	0.3333	

Third, as

Table 31 shows the modification and addition occurrence probabilities apply to periods instead of years. As a result only one modification or addition can occur in a given period. For example, the linear regression formula used for determine the probability of an addition occurring generates the probability of an addition occurring in an 18-year period when multiple addition may occur throughout that period. Therefore, multiple modification and additions that may occur are not captured by the simulation. Since standard designs experience increased LCC for each occurrence of an addition or modification, the simulation further favor standard designs in terms of lower LCC than what may actually occur. This limition can be improved in future research by increasing the sample facility size or improving the facility project records to clearly reflect all addition and modification projects.

Forth, due to the Air Force Automated Civil Engineer System (ACES) only containing facility project histories going back 1996 the simulation was only able to estimate the LCC for an 18-year period. According to Uddin, Hudson, and Haas (2013) the majority of facilities have at least a 40-year lifecycle. This means that simulation may only capture half of the facility design LCC, additions, and modifications. The simulation could be improved by collecting data from the predecessor of ACES the Base Engineer Automated Management System (BEAMS). BEAMS contains facility project information going back to the 1970s. However, a new data collection process would need to be used because the project information in BEAMS was not recorded in a similar manor as ACES.

Fifth, this research only evaluated standard, flexible, and robust designs based on LCC. However, each design has additional benefits that may influence the decision on which design to choose. For example, flexible design when compared to standard designs may reduce the amount of effort and time required to execute an addition or modification. Also, a robust design may already meet the demand requirements of standard design addition or modification and thus would require no time or effort. Therefore, this simulation may be improved by comparing the LCC and benefits of each design.

Facility Design LCC Savings: Research Question 1

When comparing flexible, robust, and standard designs for an administrative facility, the results from running the MCS for the ninety-nine different combinations of facility design characteristics show clearly that the use of flexible design results in the lowest life cycle costs in Air Force administrative facilities. The one exception is that the flexible design that had sixty percent expansion (Flexible Design, Large Capacity) capability had a higher LCC than the standard designs based on the median modification costs (Standard Design, Small Modifications). Overall, flexible designs still experience the lowest LCC, however the extent to which the facility is designed to expand can significantly affect LCC. Standard designs come in at the middle of the road, so to speak; these designs are not usually the designs that experience the lowest life cycle costs, but they are rarely the most expensive option. According to the simulation’s results, there was always a less expensive option than the robust design.

The box-plot in Figure 16 shows that the mean, median, and IQR, of the total cost percentages for average flexible facility designs are less than the other five designs. In addition Table 32 shows the average LCC rank from all 99 different combinations of facility size, number of stories, and CATCODE. From the results of the simulation, it is clear that implementing flexible facility designs would indeed be the least expensive design option for Air Force facilities in terms of LCC.

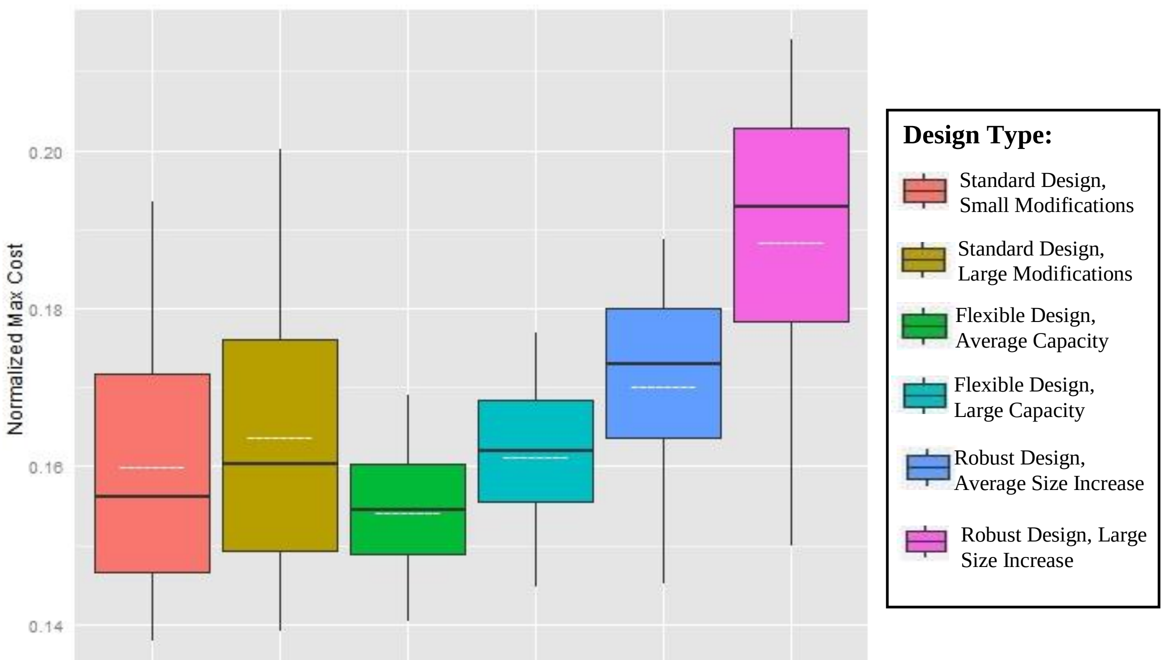


Figure 16: Overall LCC Percentage Results

Table 32: Summary of Ranked Facility Design LCC Results

Design	Size	Means	Median	Std Dev	IQR	Overall
Flexible	Average	1.9091	2.0303	1.0404	1.7677	1.6869
Standard	Median	2.4545	2.3030	3.9899	2.2727	2.7551
Flexible	Large	2.8081	2.8990	2.4343	3.9394	3.0202

Robust	Average	4.4040	4.4949	2.7980	3.4040	3.7753
Standard	Mean	3.7879	3.5758	5.0505	3.8687	4.0707
Robust	Large	5.6364	5.6970	5.6869	5.7475	5.6919

Choosing A Facility Design: Research Question Two

While it is generally true that flexible designs will save the Air Force money, flexible designs are not the best option in all circumstances. Immediately, the results eliminate robust designs, because they did not result in the least expensive design under any of the simulation inputs. Choosing between standard and flexible designs depends upon specific facility characteristics. Figure 17 shows the percentage LCC box-plots for each of the eleven different CATCODE inputs. Interactions between the facility inputs of CATCODE, size, and number of stories may produce results that are not representative of the overall LCC percentages. However, the results between different CATCODEs mirror the overall LCC percentage results. This means that CATCODEs are less significant in choosing the design that produces the lowest lifecycle costs compared to facility size and the number of stories.

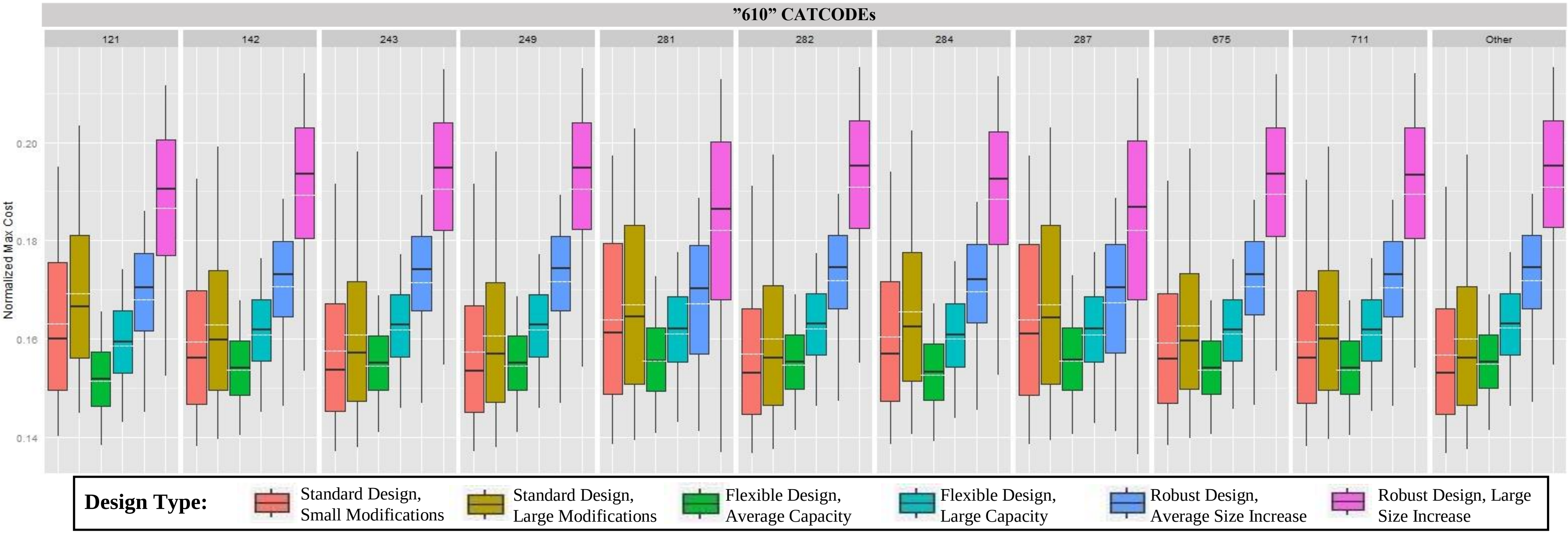


Figure 17: Results CATCODE Simulation Input

The interaction between facility size and the number of stories is the best indicator of when flexible designs and standard designs will result in the lowest LCC. The box-plots in Figure 18 show that standard designs may be a better choice when there are one or two stories in a facility, and the facility size is greater than 9,000 sq-ft. Under these facility characteristics the mean, median, and IQR of standard designs are less than flexible designs. However, the ninety percent confidence interval for standard designs in both situations shows the potential that the LCC of standard designs may exceed the LCC that flexible designs would experience. For all facilities greater than two stories, flexible design resulted in the lowest mean, median, IQR, and ninety percent confidence interval, meaning that flexible design is clearly the optimal choice. For one-story and two-story facilities that are less than 9,000 sq-ft, the summary statistics between standard design and flexible design are much closer. The similarity means that neither design has a significant advantage over the other in terms of LCC. The results shown in Figure 18 can be used by decision makers to determine which facility designs are best suited for their requirements.

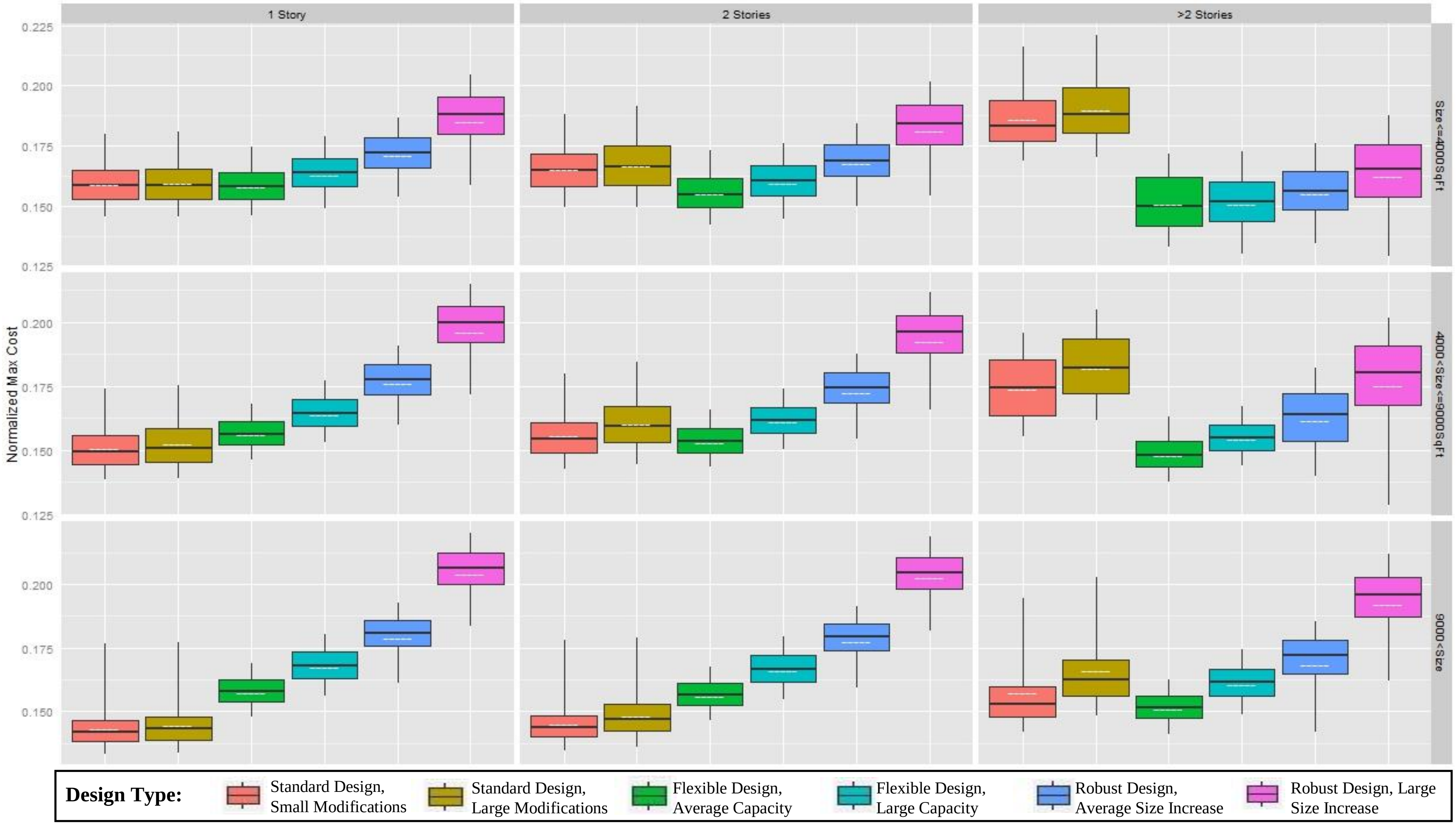


Figure 18: Results for Simulation Inputs Number of Stories and Facility Size

By focusing on the design that had the lowest mean, median, and IQR of the LCC simulation results a recommendation can be made for the type of facility design that will most likely result in the lowest LCC. Table 34 shows the facility design recommendation for each combination of size and number of stories. The orange cells in the table represent the facility characteristics where a standard design would be recommended, the green cells represent the circumstances in which a flexible design would be recommended, and the clear cells represent where neither design resulted in lowest mean, median, and IQR.

Table 33: LCC Mean, Median, and IQR Facility Design Recommendations

1 Story	2 Stories	>2 Stories	Facility Size (sq-ft)
Flexible	Flexible	Flexible	**Size<=4000**
	Flexible	Flexible	**4000<Size<=9000**
Standard	Standard	Flexible	**9000<Size**

Then, by breaking down each of the 184 sample facilities into the categories of facility size and number of stories, the criteria in Table 34, and converting each cell into a percentage, a design recommendation can be made for each of the sample facilities. Table 34 shows the percentage of sample facilities in which flexible designs are recommended (green cells) and in which standard designs are recommended (orange cells). Table 35 is a summary showing the percentage of the sample facilities in which flexible design would be the recommended design choice, and the percentage of the sample facilities in which standard design is the best option. As indicated by table 35, flexible design was the recommended choice for 41.85 percent of the sample facilities, because they had the greatest opportunity to produce the lowest LCC. The conclusion that can be drawn from these recommendations, because the Air Force produces mostly standard designs, is that if the sample is a true representation of the actual population of Air Force administrative facilities, the Air Force failed to capitalize on potential cost savings on nearly 41.85 percent of its administrative facilities.

Table 34: Facilities Samples by Size and Stories

1 Story	2 Stories	>2 Stories	Facility Size (sq-ft)
27.17%	4.35%	0.00%	**Size<=4000**
18.48%	3.80%	1.63%	**4000<Size<=9000**
26.63%	13.04%	4.89%	**9000<Size**

Table 35: Facility Design Recommendation for Sample Facilities

Best LCC Mean, Median, and IQR	
% of Sample	**Facility Design**
41.85%	Flexible
39.67%	Standard

Recommendations

The simulation created for this research used only administrative facilities, however, the methodology would work for all types of Air Force facilities, provided that adequate facility project histories exist. The parametric cost estimating system (PACES) is already capable of generating cost estimates for all types of Air Force facilities. The Monte Carlo simulation (MCS) used in the simulation can also be used to evaluate all types of facility designs and is the best way to capture uncertainty, because many Air Force facilities face a great deal of uncertainty throughout their life cycles, further research using this method could be invaluable. Air Force Civil Engineers can apply this method when evaluating facility designs, but that is only a starting place, the only limit to the usefulness of this tool is an engineer's imagination and available predictive data. Radom numbers can be used to predict response to natural disasters, show points of vulnerability, and test security. For example, MSC can be used to predict the probability of a natural disaster, such as a blizzard or hurricane occurring, and furthermore predict the impact that these types of events could have on an Air Force installation. From these predictions, readiness plans can be made.

Areas of future research that would be beneficial to continuing this line of inquiry would be improving the simulation's ability to predict facility demands, and evaluating the benefits to cost ratio for each design. Research conducted on the LCC demands of flexible facilities is limited, further research in this area is needed to determine if the frequency of additions increases when using a flexible design. Further recommendations for changes in the current design process that is used by the Air Force are to think of facility costs in terms of LCC, change regulations to allow facilities to be designed for uncertain future demands, and evaluate multiple facility designs over a range of demands. To improve future research conducted on Air Force facilities, it would be helpful for there to be an increased focus on documentation accuracy and consistency during the facility design and modification processes.

Process Changes Needed

The current rate of facility demand changes is increasing and aging inflexible infrastructure often results in expensive modifications (United States Air Force, 2015).

When demand changes occur, flexible facilities can be more beneficial then both standard and robust designs. Flexible facilities experience lower operational cost like standard design but have the capability to meet future facility demands at reduced cost, time, and effort. Unfortunately, current facility design practices do not support the creation of flexible designs. The implementation of flexible design requires three changes to the current design practice: funding new facilities based on LCC, using ranges rather than point estimates to predict demands and costs, and designing for variation instead of a specification.

The current practice of the Air Force is to calculate the cost of a facility by determining the cost of the design and construction. While the initial costs associated with a facility are important factors it often produces facilities that are cheaper to construct but more expensive to maintain. As Figure 1 shows, initial construction cost only consist of 34% on average of the LCC and operational costs makeup the remaining 66%. While the initial facility cost is important, it is only one part of the facility's LCC and the current facility construction process often increases LCC in order to reduce the initial construction costs. By funding projects based on their description and LCC, the Air Force can reduce facility costs and make smart lifecycle investments. Energy usage is an example of a potentially beneficial lifecycle factor. Strategies to lower energy consumption may cost more than standard equipment initially, but the annual reduced energy costs may contribute significantly to decreasing LCC. Facility design practices need to consider the expected overall LCC to choose an optimal facility investment.

The “Flaw of Averages” is one of the biggest problems with current standard design practices. In facilities, the flaw of average often occurs by assuming facility demands will be the same as the average demand of other similar facilities (de Neufville & Scholtes, 2011). The “Flaw of Averages” in designing a facility leads to cost overruns or underutilization. When predicting the demand of a future facility, it is common practice to estimate the demand based on the average demand of similar facilities. For example, if two similar facilities have a demand to support 50 and 150 personnel, then the new facility design is for an estimated demand of 100. Designing the facility to 100 personnel is a mistake because the estimate assumes that the new facility will have a static level of demand. If demand ends up being fifty, then the facility becomes underutilized. If the demand ends up being 150, then the facility cannot meet the requirement without an expensive addition. In most cases in standard design practices, the “Flaw of Averages” results from point estimates (Savage, 2012) or designing to specification (de Neufville & Scholtes, 2011).

Second, when designing a facility, there exists a large range of demand uncertainty. Estimates are required for all facility demands. For every estimate, there exists some amount of uncertainty. Current practices design a facility around point estimates of future demand (de Neufville & Scholtes, 2011). A point estimate is a prediction represented by a single number (Ang & Tang, 2007). For example, a facility design needs to support 200 personnel. The 200 personnel is a point estimate. Facility demands estimates are important because designers use them to ensure the design for the facility will meet user criteria. Therefore, it is important to ensure the estimates are accurate. However, though they are common practice point estimates are rarely accurate. Using of ranges to express facility demand and cost estimates is more accurate method of selecting the best design (de Neufville & Scholtes, 2011). Demands and costs expressed in ranges rather than cost estimates allow designers to accommodate more for uncertainty, and thus produce a more flexible design.

Third, standard practices "*design to specification* when it should *design for variation*" (de Neufville & Scholtes, 2011, p. 5). Current practices design to specification because of the use of point estimates in facility demand. Engineers design the facility to meet, but not to exceed the demand point estimate. If the actual demand is over the initial estimate, the facility may not be able to accommodate. With demand and cost expressed as ranges of possible changes, designers can create flexible designs by designing for variation. For example, consider a large open administration area that the current user needs reconfigured into two offices and a reception area. The renovation would involve installing walls for the offices and an entry door into the reception area. The construction sounds simple; however, fire suppression, heating and air-conditioning, and lighting, would all require a redesign in addition to the structural wall and door work. A flexible design method approach is designing the original administration area knowing that a reconfiguration request may occur later in the building's lifecycle. Designing for variation, instead of specification, enables the use of flexible designs. Thus decreasing the construction cost, time, and scope, in the event of a renovation or addition.

Conclusion

This research set out to show that if the Air Force changed their status quo of building standard and robust designs and instead invested in flexible facilities that can be easily adapted to changing demands, significant cost savings can be achieved. The results of the simulation show that flexible facilities with the ability to expand to thirty-six percent beyond the initial requirements will result in LCC savings. The simulation also shows that under no circumstances do robust designs result in the lowest LCC and this makes a strong argument in favor of changing the current design practices currently being used by the Air Force. The simulation showed a mean 91.5 percent accuracy in predicting facility modifications and additions, the majority of that accuracy comes from predicting that a modification or addition does not occur. The simulation is only 27.4 percent accurate at predicting the occurrence of a modification or addition, any modifications or additions would add to the standard design costs significantly more than for the flexible or robust designs. In addition, the simulation is only able to predict one modification or addition in a fixed period of time, when in reality, multiple modifications or additions may occur in this fixed time period. The simulation is only able to calculate an eighteen year LCC, however the average lifecycle of an Air Force facility is forty years, thus the simulation is unable to consider more than half of the potential modifications and additions. For these reasons, the results of the simulation slightly favor standard designs, making the fact that the simulation still shows that flexible designs are more optimal than other design choices even more significant. The conclusion of this research is that it would be in the best interest of the Air Force to evaluate multiple facility designs over a range of demands based on LCC.

Through the course of this research it became clear that the amount of uncertainty faced by Air Force facilities during their projected 40 year life cycles is an area of vulnerability facing Air Force Civil Engineers. At the current time facility requirements beyond the first three to five years is not even considered. However, this research indicates that not only should the Air Force take planning for uncertainty into consideration when comparing facility designs, but by using this simulation they have the capabilities to do so. By embracing the ability to plan for uncertainty in terms of facilities, the Air Force can save itself much of the time and cost associated with demand changes. By considering the uncertainty in facility demands the Air Force can make smart investments in facilities that have the capability to adapt to uncertainty and change at reduced LCC. In addition, Civil Engineers can embrace the main objective of the Strategic Master Plan (SMP) (2015) and answer the call of the Secretary of the Air Force and Chief of Staff of the Air Force by constructing flexible facilities which can met the changing needs of the Air Force.

Appendix A: LCC Estimates Using PACES and CostLab

Facility ID	Placed in Service	Facility Size (sq-ft)	Construction Cost	Total 40 Year Operational Cost			Construction Cost Percentage	Operational Cost Percentage		
				M&R	Operations	Recap		M&R	Operations	Recap
2	1996	6940	$2,464,921.38	$2,150,280	$2,131,880	$778,760	0.3275	0.2857	0.2833	0.1035
3	2010	113864	$23,265,458.52	$4,882,720	$28,102,200	$12,671,760	0.3376	0.0708	0.4077	0.1839
4	2011	8030	$2,381,779.61	$753,160	$2,383,600	$1,134,440	0.3580	0.1132	0.3583	0.1705
5	2003	11749	$3,505,657.30	$2,959,560	$3,380,760	$1,393,720	0.3119	0.2633	0.3008	0.1240
6	2005	143292	$29,529,796.07	$11,334,680	$34,821,880	$14,693,200	0.3267	0.1254	0.3853	0.1626
7	2010	24196	$5,708,699.10	$1,800,280	$6,455,920	$2,924,680	0.3380	0.1066	0.3822	0.1732
8	2006	52488	$11,355,828.29	$4,794,080	$13,352,600	$5,544,600	0.3240	0.1368	0.3810	0.1582
9	2007	1833	$1,019,915.11	$505,840	$907,040	$266,800	0.3778	0.1874	0.3360	0.0988
10	1996	7389	$2,244,808.48	$1,595,640	$2,235,640	$824,040	0.3253	0.2312	0.3240	0.1194
11	2002	14976	$3,900,127.93	$3,195,080	$4,119,120	$1,693,320	0.3022	0.2475	0.3191	0.1312
12	2002	132712	$25,572,992.60	$15,847,000	$32,405,960	$12,958,040	0.2947	0.1826	0.3734	0.1493
13	2002	27141	$6,463,922.09	$4,948,560	$7,125,320	$2,838,640	0.3024	0.2315	0.3333	0.1328
14	2002	4000	$1,509,614.89	$922,640	$1,449,480	$517,240	0.3432	0.2097	0.3295	0.1176
15	2011	168490	$36,183,492.71	$20,442,880	$41,323,280	$16,450,400	0.3163	0.1787	0.3612	0.1438
16	2008	12813	$3,375,657.36	$1,771,720	$3,624,480	$1,631,120	0.3245	0.1703	0.3484	0.1568
17	1996	3400	$1,368,992.30	$708,120	$1,309,480	$402,560	0.3613	0.1869	0.3456	0.1062
18	1999	7265	$2,757,331.93	$2,730,200	$2,207,000	$852,320	0.3226	0.3194	0.2582	0.0997
19	2013	18181	$4,885,891.60	$1,350,360	$4,850,240	$2,396,640	0.3624	0.1002	0.3597	0.1778
20	2004	8913	$2,543,357.88	$2,159,440	$2,634,480	$1,110,560	0.3011	0.2556	0.3119	0.1315
21	1998	38487	$8,499,163.69	$4,744,880	$9,703,880	$3,639,200	0.3197	0.1785	0.3650	0.1369
22	2000	10320	$2,846,422.09	$2,219,240	$2,958,120	$1,184,360	0.3091	0.2410	0.3213	0.1286
23	2003	2880	$1,245,393.97	$750,440	$1,164,280	$385,600	0.3512	0.2116	0.3284	0.1088

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Facility ID	Placed in Service	Facility Size (sq-ft)	Construction Cost	Total 40 Year Operational Cost			Construction Cost Percentage	Operational Cost Percentage		
				M&R	Operations	Recap		M&R	Operations	Recap
24	2003	2640	$1,188,122.14	$733,600	$1,108,120	$354,920	0.3510	0.2167	0.3274	0.1049
25	1999	3000	$1,262,014.68	$599,440	$1,192,360	$375,520	0.3680	0.1748	0.3477	0.1095
26	1997	3844	$1,453,425.11	$718,280	$1,413,120	$459,240	0.3594	0.1776	0.3494	0.1136
27	1996	12758	$3,366,048.71	$2,396,400	$3,611,920	$1,335,800	0.3143	0.2237	0.3372	0.1247
28	2011	3995	$1,796,648.52	$679,240	$1,448,320	$598,480	0.3973	0.1502	0.3202	0.1323
29	2011	2347	$1,421,470.26	$576,080	$1,039,480	$361,400	0.4183	0.1695	0.3059	0.1063
30	2011	119368	$24,277,729.64	$4,628,240	$29,358,920	$13,502,040	0.3383	0.0645	0.4091	0.1881
31	2005	4387	$1,567,948.89	$826,520	$1,539,640	$592,120	0.3464	0.1826	0.3402	0.1308
32	2008	2781	$1,225,430.89	$634,800	$1,141,120	$404,720	0.3598	0.1864	0.3350	0.1188
33	2012	5328	$1,752,777.66	$628,400	$1,758,400	$794,680	0.3552	0.1274	0.3564	0.1611
34	1998	15600	$4,355,012.45	$3,185,880	$4,261,600	$1,643,280	0.3239	0.2369	0.3169	0.1222
35	2014	2514	$1,421,172.80	$579,160	$1,078,600	$405,400	0.4079	0.1662	0.3096	0.1163
36	2007	7253	$2,210,722.22	$1,089,160	$2,204,240	$969,880	0.3415	0.1682	0.3405	0.1498
37	2011	13202	$3,444,216.54	$1,126,600	$3,713,520	$1,758,200	0.3430	0.1122	0.3698	0.1751
38	2005	2123	$1,331,429.31	$695,000	$986,920	$297,560	0.4021	0.2099	0.2981	0.0899
39	2003	16606	$4,168,947.70	$3,400,040	$4,491,160	$1,882,120	0.2990	0.2439	0.3221	0.1350
40	2014	3389	$1,399,975.76	$539,960	$1,306,920	$538,480	0.3698	0.1426	0.3453	0.1423
41	2005	1200	$892,444.11	$465,280	$758,200	$171,000	0.3902	0.2035	0.3315	0.0748
42	2007	3258	$1,361,936.44	$733,280	$1,276,320	$462,720	0.3552	0.1912	0.3329	0.1207
43	1997	5325	$1,752,380.50	$1,409,840	$1,757,680	$621,680	0.3162	0.2544	0.3172	0.1122
44	2005	5193	$1,731,782.17	$872,320	$1,727,040	$692,240	0.3447	0.1737	0.3438	0.1378
45	1998	6686	$2,111,017.90	$1,451,440	$2,073,120	$777,920	0.3292	0.2263	0.3232	0.1213

Appendix A: LCC Estimates Using PACES and CostLab

Facility ID	Placed in Service	Facility Size (sq-ft)	Construction Cost	Total 40 Year Operational Cost			Construction Cost Percentage	Operational Cost Percentage		
				M&R	Operations	Recap		M&R	Operations	Recap
46	2009	3816	$1,449,523.80	$766,240	$1,406,560	$554,880	0.3470	0.1834	0.3367	0.1328
47	2011	209000	$43,954,424.96	$7,286,760	$51,037,240	$23,636,560	0.3491	0.0579	0.4053	0.1877
48	2010	2400	$1,145,699.98	$473,280	$1,051,880	$363,240	0.3776	0.1560	0.3467	0.1197
49	1999	3480	$1,383,262.00	$709,680	$1,328,160	$432,120	0.3590	0.1842	0.3447	0.1121
50	2001	3480	$1,383,262.00	$888,720	$1,328,160	$446,480	0.3418	0.2196	0.3282	0.1103
51	1998	7328	$2,220,275.45	$1,590,800	$2,221,560	$845,080	0.3228	0.2313	0.3230	0.1229
52	1998	5107	$1,719,209.86	$1,289,000	$1,707,080	$608,040	0.3230	0.2421	0.3207	0.1142
53	2010	21218	$5,206,699.49	$1,833,760	$5,778,560	$2,608,680	0.3375	0.1189	0.3746	0.1691
54	2005	136165	$28,100,174.45	$10,891,280	$33,194,440	$13,962,680	0.3262	0.1264	0.3853	0.1621
55	2003	3236	$1,328,003.24	$729,360	$1,271,200	$445,000	0.3519	0.1933	0.3369	0.1179
56	2008	4904	$1,706,409.86	$859,800	$1,659,880	$689,600	0.3471	0.1749	0.3377	0.1403
58	2011	25718	$6,663,017.74	$1,734,480	$6,517,760	$3,136,000	0.3691	0.0961	0.3611	0.1737
59	2012	10800	$3,381,111.42	$950,360	$3,068,320	$1,499,560	0.3799	0.1068	0.3448	0.1685
60	2007	2200	$1,097,284.82	$594,480	$1,005,000	$318,160	0.3640	0.1972	0.3333	0.1055
61	2007	21505	$5,137,723.63	$2,587,040	$5,843,880	$2,513,080	0.3195	0.1609	0.3634	0.1563
62	2007	2790	$1,229,358.30	$634,000	$1,143,200	$399,400	0.3609	0.1861	0.3356	0.1173
63	1996	106900	$21,940,446.91	$9,235,520	$26,512,160	$9,466,360	0.3267	0.1375	0.3948	0.1410
64	2002	140000	$29,607,136.16	$17,160,480	$34,070,160	$13,669,280	0.3133	0.1816	0.3605	0.1446
65	2012	1349	$913,826.61	$372,520	$793,240	$214,920	0.3983	0.1624	0.3457	0.0937
66	2003	18304	$4,485,738.73	$3,524,120	$4,878,280	$2,047,400	0.3003	0.2360	0.3266	0.1371
67	2000	8962	$2,953,431.63	$2,182,520	$2,645,760	$1,045,400	0.3346	0.2473	0.2997	0.1184
68	2005	94578	$21,201,620.78	$7,605,240	$23,236,000	$9,706,000	0.3434	0.1232	0.3763	0.1572

Appendix A: LCC Estimates Using PACES and CostLab

Facility ID	Placed in Service	Facility Size (sq-ft)	Construction Cost	Total 40 Year Operational Cost			Construction Cost Percentage	Operational Cost Percentage		
				M&R	Operations	Recap		M&R	Operations	Recap
69	2008	24343	$5,878,467.21	$2,773,120	$6,489,320	$2,845,720	0.3268	0.1542	0.3608	0.1582
70	2008	2400	$1,172,642.63	$609,320	$1,051,880	$351,560	0.3681	0.1913	0.3302	0.1104
71	2010	27150	$6,317,912.60	$2,047,960	$7,127,400	$3,235,840	0.3373	0.1093	0.3806	0.1728
72	2002	39837	$9,306,412.99	$6,280,560	$10,010,840	$4,010,040	0.3143	0.2121	0.3381	0.1354
73	2001	5000	$1,681,609.59	$1,522,960	$1,682,200	$626,200	0.3050	0.2763	0.3051	0.1136
74	2010	2560	$1,174,941.41	$475,720	$1,089,360	$386,400	0.3758	0.1522	0.3484	0.1236
75	2001	71794	$16,207,694.13	$9,714,640	$17,894,760	$6,922,280	0.3194	0.1915	0.3527	0.1364
76	2004	12640	$4,288,056.37	$3,020,920	$3,584,880	$1,509,960	0.3457	0.2435	0.2890	0.1217
77	2014	194298	$41,163,739.57	$6,761,200	$47,216,760	$23,077,360	0.3482	0.0572	0.3994	0.1952
78	1997	8304	$2,419,203.74	$1,629,560	$2,446,800	$930,040	0.3258	0.2195	0.3295	0.1252
79	1998	24534	$5,915,058.41	$3,544,240	$6,532,760	$2,433,480	0.3210	0.1924	0.3545	0.1321
80	2011	10000	$2,755,159.31	$805,040	$2,884,560	$1,378,640	0.3522	0.1029	0.3687	0.1762
81	1997	65105	$14,097,129.18	$6,147,520	$16,369,480	$5,892,640	0.3316	0.1446	0.3851	0.1386
82	2002	1536	$970,629.41	$551,760	$837,240	$207,120	0.3782	0.2150	0.3262	0.0807
83	2007	3800	$1,447,654.66	$764,680	$1,402,840	$534,920	0.3488	0.1843	0.3380	0.1289
84	2002	132430	$27,403,616.88	$16,635,840	$32,341,560	$12,930,560	0.3068	0.1863	0.3621	0.1448
85	2002	7548	$2,267,929.31	$1,943,800	$2,272,360	$926,480	0.3060	0.2623	0.3066	0.1250
86	2007	4993	$1,680,189.32	$863,560	$1,680,560	$689,800	0.3419	0.1757	0.3420	0.1404
87	2013	29354	$6,734,844.87	$1,824,560	$7,628,240	$3,641,360	0.3396	0.0920	0.3847	0.1836
88	2006	2805	$1,260,839.57	$634,320	$1,146,720	$394,920	0.3669	0.1846	0.3337	0.1149
89	2006	26630	$6,350,793.20	$2,999,960	$7,009,200	$2,979,960	0.3284	0.1551	0.3624	0.1541
90	2002	7090	$2,728,145.14	$1,984,840	$2,166,560	$875,680	0.3518	0.2559	0.2794	0.1129

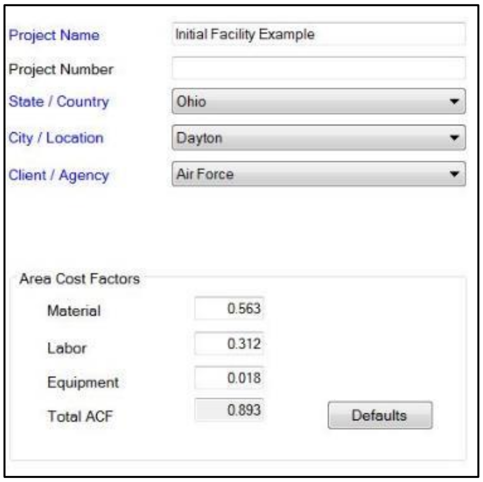
Appendix A: LCC Estimates Using PACES and CostLab

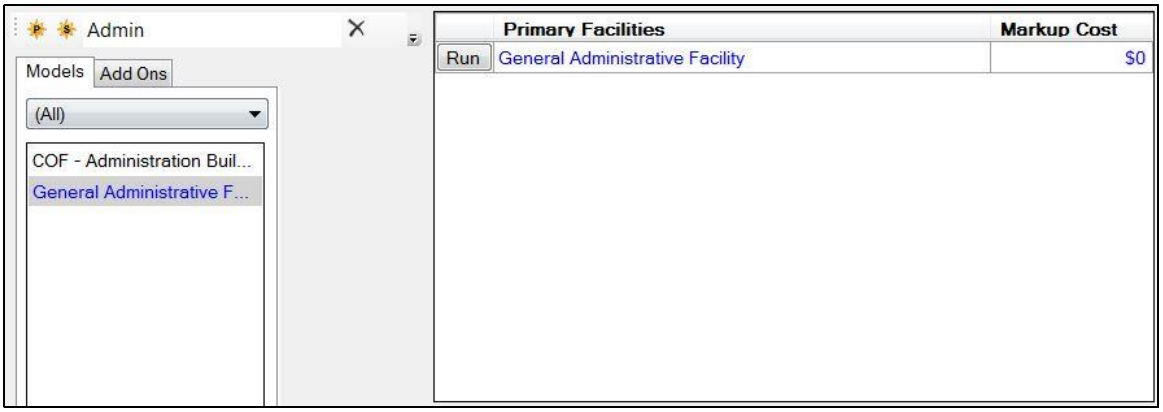
Facility ID	Placed in Service	Facility Size (sq-ft)	Construction Cost	Total 40 Year Operational Cost			Construction Cost Percentage	Operational Cost Percentage		
				M&R	Operations	Recap		M&R	Operations	Recap
91	2000	8000	$2,359,127.01	$1,950,280	$2,376,680	$944,720	0.3092	0.2556	0.3115	0.1238
92	2001	10325	$2,846,841.41	$2,259,840	$2,959,240	$1,204,360	0.3071	0.2438	0.3192	0.1299
93	2006	11066	$3,010,980.22	$1,348,080	$3,129,400	$1,388,920	0.3392	0.1519	0.3525	0.1565
94	2005	2369	$1,140,796.37	$605,920	$1,044,640	$330,600	0.3654	0.1941	0.3346	0.1059
95	2010	25855	$6,055,084.40	$1,909,400	$6,833,040	$3,099,600	0.3383	0.1067	0.3818	0.1732
96	2003	32490	$7,361,984.39	$5,382,000	$8,340,840	$3,386,160	0.3008	0.2199	0.3408	0.1384
97	1999	18119	$4,584,504.64	$2,700,280	$4,836,120	$1,901,160	0.3269	0.1926	0.3449	0.1356
98	2001	130447	$29,649,401.33	$15,440,080	$31,888,720	$12,530,720	0.3312	0.1725	0.3563	0.1400
99	2005	20000	$5,243,378.40	$2,480,920	$5,501,360	$2,284,000	0.3381	0.1600	0.3547	0.1473
100	2011	28500	$6,571,319.35	$1,859,000	$7,434,160	$3,433,240	0.3405	0.0963	0.3852	0.1779
101	2012	3000	$1,262,014.68	$472,640	$1,192,360	$464,320	0.3721	0.1394	0.3516	0.1369
102	2006	22500	$5,380,723.77	$2,659,200	$6,070,240	$2,571,480	0.3226	0.1594	0.3639	0.1542
103	2002	4480	$1,583,983.02	$1,490,440	$1,561,280	$574,920	0.3040	0.2860	0.2996	0.1103
104	2002	3773	$1,442,951.80	$907,280	$1,396,560	$489,680	0.3406	0.2142	0.3297	0.1156
105	1996	11476	$3,085,729.55	$1,860,880	$3,223,440	$1,217,840	0.3287	0.1982	0.3434	0.1297
106	1996	5336	$1,811,700.21	$1,412,320	$1,760,240	$612,760	0.3237	0.2523	0.3145	0.1095
107	1996	21026	$5,063,544.91	$3,429,120	$5,734,880	$2,059,160	0.3109	0.2105	0.3521	0.1264
108	1996	1483	$1,169,922.45	$1,015,480	$824,800	$181,480	0.3666	0.3182	0.2584	0.0569
109	1997	3674	$1,427,746.48	$713,640	$1,373,440	$440,160	0.3610	0.1804	0.3473	0.1113
110	1997	18489	$5,391,981.77	$3,881,800	$4,920,440	$1,872,520	0.3356	0.2416	0.3063	0.1165
111	2005	27856	$6,444,106.58	$3,066,880	$7,287,840	$3,050,440	0.3247	0.1545	0.3672	0.1537
112	2003	8692	$2,509,479.98	$2,025,920	$2,536,240	$1,068,440	0.3083	0.2489	0.3116	0.1313

Appendix A: LCC Estimates Using PACES and CostLab

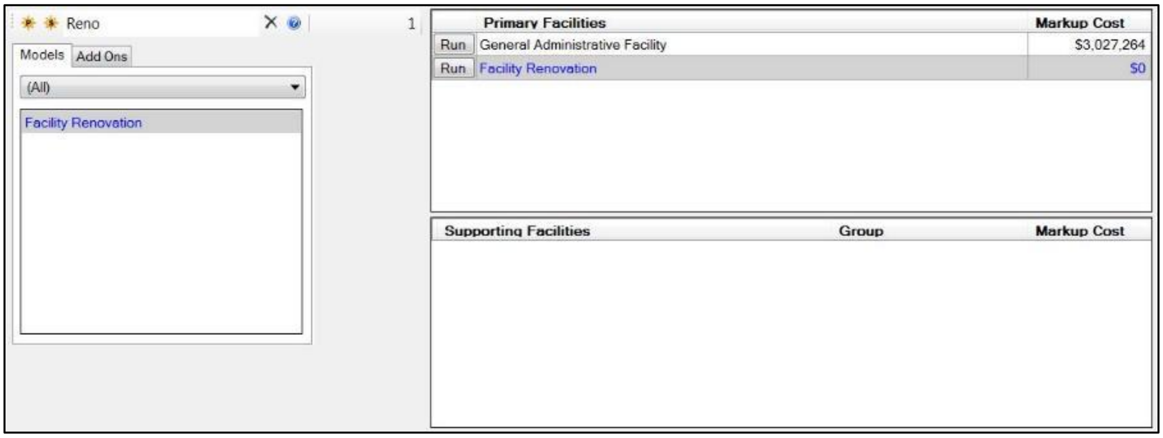
Facility ID	Placed in Service	Facility Size (sq-ft)	Construction Cost	Total 40 Year Operational Cost			Construction Cost Percentage	Operational Cost Percentage		
				M&R	Operations	Recap		M&R	Operations	Recap
113	2006	60162	$12,826,501.71	$5,521,520	$15,242,800	$6,321,720	0.3214	0.1383	0.3819	0.1584
114	1996	30191	$7,088,426.82	$4,009,640	$7,818,440	$2,828,400	0.3260	0.1844	0.3596	0.1301
115	2013	1109	$856,559.85	$364,720	$736,760	$180,400	0.4006	0.1706	0.3445	0.0844
116	1996	2805	$1,231,877.80	$594,120	$1,146,720	$335,440	0.3724	0.1796	0.3466	0.1014
117	2010	119368	$24,277,729.64	$4,994,520	$29,358,920	$13,283,280	0.3376	0.0695	0.4082	0.1847
118	1997	7262	$2,212,191.06	$1,581,160	$2,206,320	$824,640	0.3242	0.2317	0.3233	0.1208
119	2003	24439	$6,240,322.95	$4,458,080	$6,511,160	$2,631,600	0.3145	0.2247	0.3282	0.1326
120	2000	6385	$2,353,896.90	$1,795,000	$2,003,440	$770,800	0.3400	0.2593	0.2894	0.1113
121	2011	45226	$10,159,752.31	$2,362,400	$11,236,520	$5,226,160	0.3505	0.0815	0.3877	0.1803

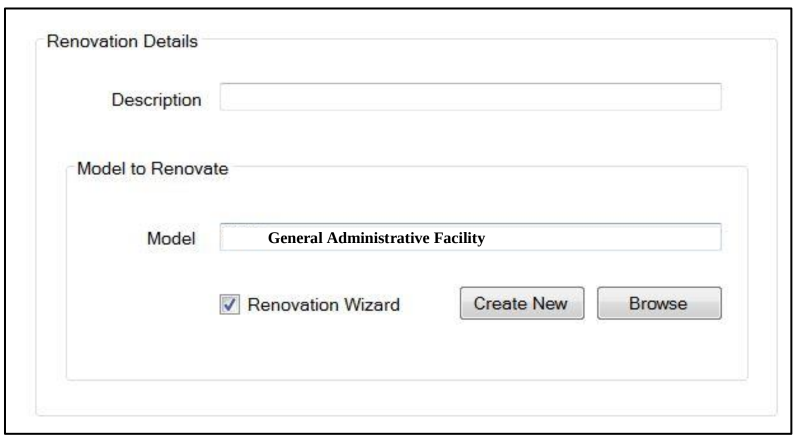
Appendix B: PACES Initial Construction, Addition, and Modification Estimation Process

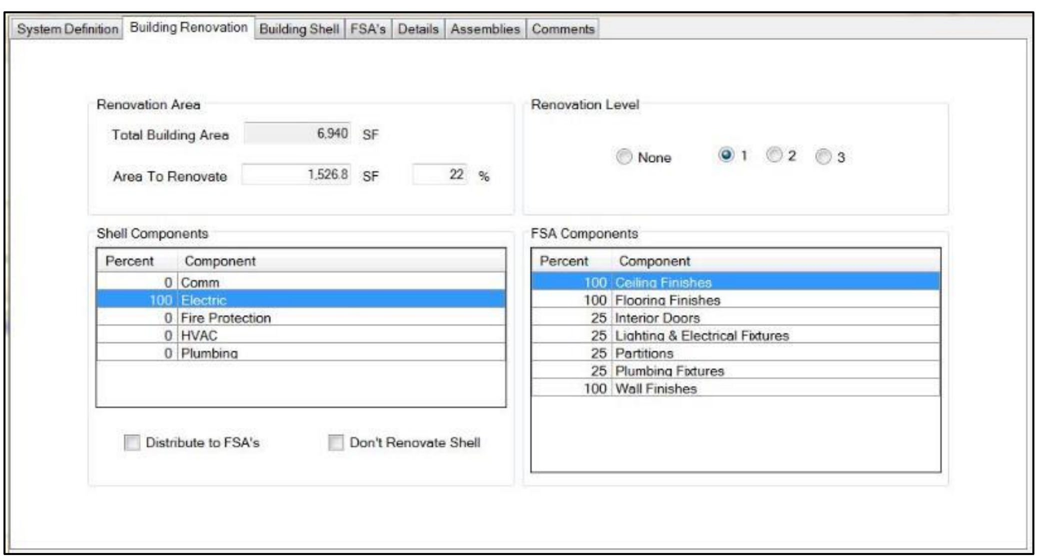




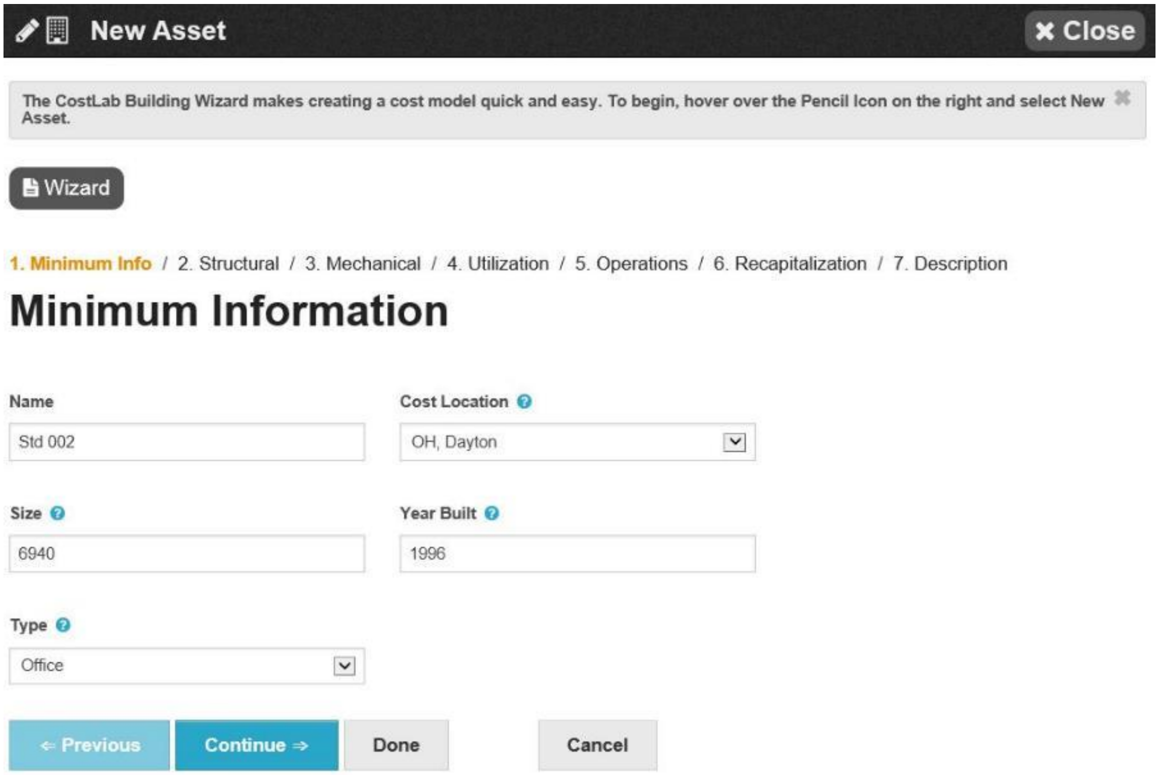
Appendix B: PACES Initial Construction, Addition, and Modification Estimation Process



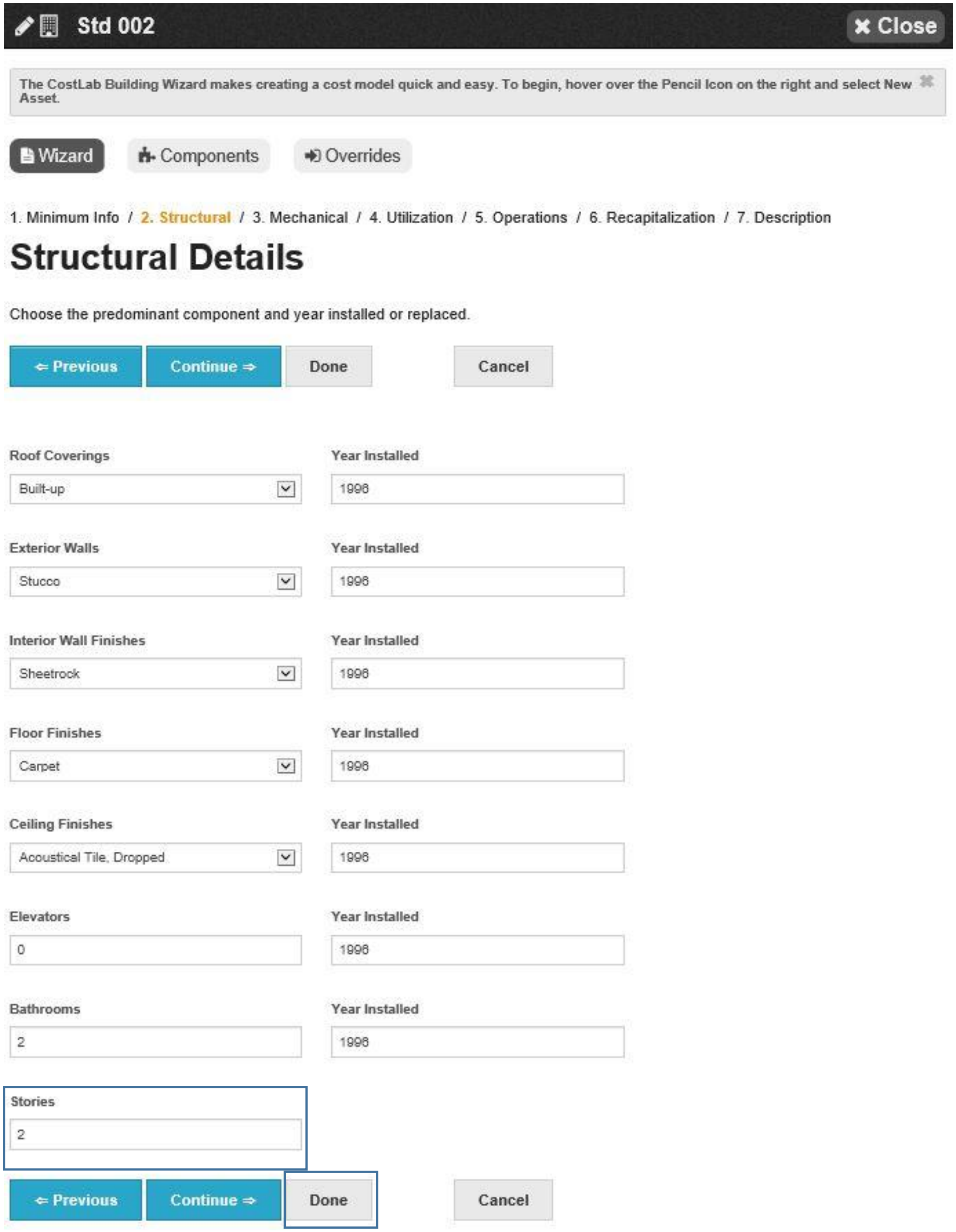




Appendix C: CostLab Operational Cost Estimation Process



Appendix C: CostLab Operational Cost Estimation Process



Appendix C: CostLab Operational Cost Estimation Process

My Assets | My Projects | Cost Library | Reports | Preferences | Help | Log off

CostLab

My Campus (view in My Assets)

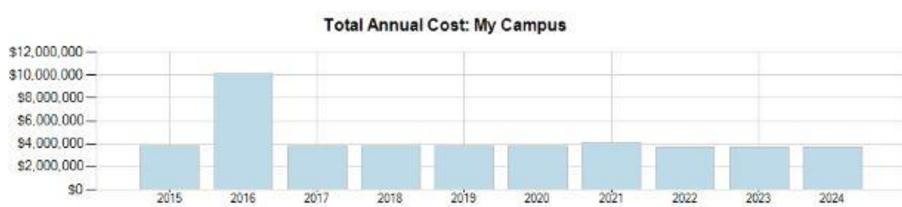
Hover over the report title to view detailed estimated of Average, Annual, and Deferred Costs. Quickly drill-down for additional detail by clicking on a hyperlinked folder or asset name.

My Campus ▾ | Total Annual Cost ▾

Total size:	423,392 Sq Ft	**Total PRV:**	$83,440,055
Number of assets:	3		

2015 - 2024 | 2025 - 2034 | 2035 - 2044 | 2045 - 2054 | 2055 - 2064

My Assets	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Total
063 Robust Avg	$1,301,626	$3,374,540	$1,294,818	$1,286,663	$1,279,734	$1,304,430	$1,391,608	$1,265,818	$1,266,873	$1,265,143	$15,031,253
063 Robust Max	$1,540,660	$4,232,662	$1,532,737	$1,523,359	$1,514,932	$1,542,748	$1,651,971	$1,498,861	$1,499,305	$1,498,793	$18,036,028
063 Std	$978,739	$2,524,521	$974,713	$968,162	$962,649	$984,426	$1,050,783	$952,841	$953,478	$953,197	$11,303,509
Total	**$3,821,025**	**$10,131,723**	**$3,802,268**	**$3,778,184**	**$3,757,315**	**$3,831,604**	**$4,094,362**	**$3,717,520**	**$3,719,656**	**$3,717,133**	**$44,370,790**



All costs expressed in $2015 USD.

Appendix C: CostLab Operational Cost Estimation Process

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My Campus (view in My Assets)

Hover over the report title to view detailed estimated of Average, Annual, and Deferred Costs. Quickly drill-down for additional detail by clicking on a hyperlinked folder or asset name.

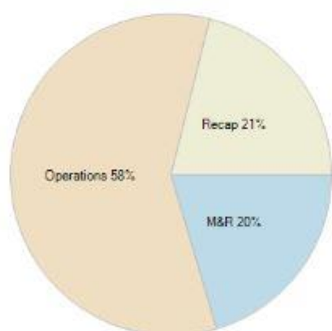
My Campus | Total Average Cost

10 years

Total size:	423,392 Sq Ft	**Total PRV:**	$83,440,055
Number of assets:	3		

My Assets	Size	PRV	M&R	Operations	Recapitalization	Total	Total / Size	Total / PRV
063 Robust Avg	145,496 Sq Ft	$28,671,386	$298,004	$883,130	$321,991	$1,503,125	$10.33	5.24%
063 Robust Max	170,996 Sq Ft	$33,695,571	$377,799	$1,047,389	$378,415	$1,803,603	$10.55	5.35%
063 Std	106,900 Sq Ft	$21,073,098	$230,888	$662,804	$236,659	$1,130,351	$10.57	5.36%
Total	**423,392 Sq Ft**	**$83,440,055**	**$906,690**	**$2,593,323**	**$937,066**	**$4,437,079**	**$10.48**	**5.32%**

Total Average Cost: My Campus



All costs expressed in $2015 USD.

Appendix D: Facility Sample Modification and Addition Occurrence Percentages

System	Yr Grp	Project Occurrence Percentages																	
		Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10	Yr 11	Yr 12	Yr 13	Yr 14	Yr 15	Yr 16	Yr 17	Yr 18
Addition	1-18	0.074	0.185	0.000	0.074	0.074	0.148	0.074	0.074	0.111	0.000	0.037	0.000	0.037	0.074	0.037			
		0.815	0.741	0.556	0.556	0.481	0.407	0.259	0.185	0.111	0.111	0.148	0.148	0.185	0.259	0.296			
Comm	1-4	0.217	0.391	0.304	0.348														
		0.172	0.483	0.724	1.000														
	5-8					0.333	0.238	0.476	0.143										
						0.280	0.480	0.880	1.000										
	9-18									0.053	0.263	0.158	0.211	0.211	0.000	0.158			
										0.050	0.300	0.450	0.650	0.850	0.850	1.000			
Electric	1-6	0.212	0.333	0.364	0.152	0.121	0.091												
		0.167	0.429	0.714	0.833	0.929	1.000												
	7-18							0.280	0.080	0.240	0.120	0.000	0.120	0.120	0.080	0.040	0.000	0.040	0.040
								0.241	0.310	0.517	0.621	0.621	0.724	0.828	0.897	0.931	0.931	0.966	1.000
HVAC	1-7	0.077	0.192	0.115	0.154	0.077	0.231	0.154											
		0.077	0.269	0.385	0.538	0.615	0.846	1.000											
	8-18								0.130	0.130	0.217	0.087	0.174	0.130	0.043	0.130	0.043		
									0.120	0.240	0.440	0.520	0.680	0.800	0.840	0.960	1.000		
Plumb	1-7	0.036	0.214	0.286	0.107	0.179	0.107	0.143											
		0.033	0.233	0.500	0.600	0.767	0.867	1.000											
	8-18								0.235	0.412	0.176	0.000	0.118	0.059	0.059	0.118			
									0.200	0.550	0.700	0.700	0.800	0.850	0.900	1.000			

Appendix E: PACES Facility Design Initial Construction Cost Estimates

Fac ID	Placed In Service Year	# of Stories	Cat Nbr	Standard Facility Size	Robust Average Facility Size	Robust Large Facility Size	Standard Cost	Robust Average Cost	Robust Large Cost	Flexibility Average Cost	Flexibility Large Cost
2	1996	2	610128	6940	9446	11101	$2,464,921	$2,650,704	$3,016,846	$2,599,454	$2,875,096
3	2010	1	610284	113864	154975	182135	$23,265,459	$32,381,053	$37,479,670	$30,769,785	$34,810,186
4	2011	1	610243	8030	10929	12845	$2,381,780	$2,968,235	$3,378,833	$2,812,258	$3,130,309
5	2003	2	610811	11749	15991	18794	$3,505,657	$4,433,763	$5,005,834	$4,229,762	$4,673,035
6	2005	1	610127	143292	195028	229208	$29,529,796	$40,001,014	$46,355,584	$37,979,162	$43,028,371
7	2010	1	610284	24196	32932	38704	$5,708,699	$7,435,041	$8,549,504	$7,046,875	$7,912,823
8	2006	1	610119	52488	71439	83959	$11,355,828	$15,003,422	$17,433,404	$14,230,170	$16,143,611
9	2007	1	610144	1833	2495	2932	$1,019,915	$1,161,486	$1,252,374	$1,116,916	$1,179,460
10	1996	1	610249	7389	10057	11819	$2,244,808	$2,895,165	$3,151,035	$2,759,657	$2,921,852
11	2002	2	610241	14976	20383	23955	$3,900,128	$5,466,712	$6,262,102	$5,227,746	$5,859,248
12	2002	2	610249	132712	180628	212284	$25,572,993	$39,474,657	$45,777,850	$37,917,878	$43,120,468
13	2002	1	610286	27141	36940	43414	$6,463,922	$8,406,802	$9,675,980	$7,967,267	$8,953,842
14	2002	1	610711	4000	5444	6398	$1,509,615	$1,835,974	$2,038,017	$1,748,445	$1,897,208
15	2011	2	610281	168490	229323	269515	$36,183,493	$48,309,384	$56,008,565	$46,247,438	$52,603,630
16	2008	1	610284	12813	17439	20496	$3,375,657	$4,434,002	$4,931,272	$4,212,598	$4,566,345
17	1996	1	610144	3400	4628	5439	$1,368,992	$1,607,634	$1,793,427	$1,536,932	$1,672,916
18	1999	3	610285	7265	9888	11621	$2,757,332	$3,348,633	$3,735,009	$3,195,188	$3,488,967
19	2013	2	610127	18181	24745	29082	$4,885,892	$6,308,026	$7,165,895	$6,004,079	$6,677,131
20	2004	1	610129	8913	12131	14257	$2,543,358	$3,240,047	$3,704,217	$3,070,685	$3,433,048
21	1998	1	610129	38487	52383	61563	$8,499,164	$11,342,866	$13,075,559	$10,733,787	$12,093,707
22	2000	1	610129	10320	14046	16508	$2,846,422	$3,671,184	$4,155,614	$3,491,341	$3,856,925
23	2003	1	610281	2880	3920	4607	$1,245,394	$1,465,231	$1,528,471	$1,401,862	$1,447,153

Appendix E: PACES Facility Design Initial Construction Cost Estimates

Fac ID	Placed In Service Year	# of Stories	Cat Nbr	Standard Facility Size	Robust Average Facility Size	Robust Large Facility Size	Standard Cost	Robust Average Cost	Robust Large Cost	Flexibility Average Cost	Flexibility Large Cost
24	2003	1	610281	2640	3593	4223	$1,188,122	$1,401,362	$1,528,471	$1,340,297	$1,430,965
25	1999	1	610281	3000	4083	4799	$1,262,015	$1,505,707	$1,651,733	$1,440,492	$1,546,543
26	1997	1	610127	3844	5232	6149	$1,453,425	$1,738,744	$1,935,563	$1,661,396	$1,802,899
27	1996	1	610249	12758	17364	20408	$3,366,049	$4,314,740	$4,921,670	$4,094,083	$4,557,987
28	2011	2	610127	3995	5437	6390	$1,796,649	$2,142,947	$2,409,558	$2,053,447	$2,262,592
29	2011	2	610811	2347	3194	3754	$1,421,470	$1,625,331	$1,758,188	$1,561,290	$1,655,782
30	2011	1	610124	119368	162466	190940	$24,277,730	$33,800,595	$39,131,515	$32,105,954	$36,350,205
31	2005	1	610811	4387	5971	7017	$1,567,949	$1,892,270	$2,173,983	$1,800,512	$2,022,628
32	2008	1	610243	2781	3785	4448	$1,225,431	$1,444,920	$1,580,490	$1,381,624	$1,479,431
33	2012	1	610243	5328	7252	8523	$1,752,778	$2,210,483	$2,469,588	$2,098,870	$2,292,348
34	1998	2	610243	15600	21232	24954	$4,355,012	$5,573,633	$6,334,002	$5,306,745	$5,900,575
35	2014	2	610249	2514	3422	4021	$1,421,173	$1,643,217	$1,776,984	$1,577,810	$1,672,411
36	2007	1	610243	7253	9872	11602	$2,210,722	$2,736,268	$3,103,978	$2,601,545	$2,876,709
37	2011	1	610124	13202	17969	21118	$3,444,217	$4,426,076	$5,074,042	$4,197,234	$4,687,747
38	2005	2	610249	2123	2890	3396	$1,331,429	$1,510,177	$1,639,137	$1,453,210	$1,546,510
39	2003	1	610111	16606	22602	26563	$4,168,948	$5,397,029	$6,196,347	$5,114,605	$5,730,037
40	2014	1	610675	3389	4613	5421	$1,399,976	$1,643,480	$1,833,399	$1,571,361	$1,710,421
41	2005	1	610287	1200	1633	1920	$892,444	$1,057,790	$1,057,790	$1,004,426	$1,004,426
42	2007	1	610121	3258	4434	5211	$1,361,936	$1,614,629	$1,775,971	$1,544,561	$1,663,508
43	1997	1	610127	5325	7248	8518	$1,752,380	$2,210,062	$2,469,031	$2,098,466	$2,291,754
44	2005	1	610249	5193	7068	8307	$1,731,782	$2,184,314	$2,419,578	$2,073,509	$2,246,903
45	1998	1	610243	6686	9100	10695	$2,111,018	$2,588,546	$2,937,462	$2,463,722	$2,723,165

Appendix E: PACES Facility Design Initial Construction Cost Estimates

Fac ID	Placed In Service Year	# of Stories	Cat Nbr	Standard Facility Size	Robust Average Facility Size	Robust Large Facility Size	Standard Cost	Robust Average Cost	Robust Large Cost	Flexibility Average Cost	Flexibility Large Cost
46	2009	1	610112	3816	5194	6104	$1,449,524	$1,731,971	$1,929,514	$1,656,090	$1,797,534
47	2011	2	610243	209000	284460	334314	$43,954,425	$58,826,198	$67,079,663	$56,310,401	$62,924,936
48	2010	1	610243	2400	3267	3839	$1,145,700	$1,331,807	$1,452,836	$1,275,615	$1,362,756
49	1999	1	610119	3480	4736	5567	$1,383,262	$1,827,635	$1,815,607	$1,666,807	$1,694,160
50	2001	1	610144	3480	4736	5567	$1,383,262	$1,637,104	$1,815,607	$1,566,375	$1,694,160
51	1998	1	610127	7328	9974	11722	$2,220,275	$2,751,856	$3,135,489	$2,617,244	$2,907,642
52	1998	1	610144	5107	6951	8169	$1,719,210	$2,149,285	$2,401,873	$2,039,733	$2,231,255
53	2010	1	610127	21218	28879	33940	$5,206,699	$6,797,620	$7,803,042	$6,444,318	$7,226,362
54	2005	1	610915	136165	185327	217808	$28,100,174	$38,101,591	$44,225,109	$36,194,451	$41,062,350
55	2003	1	610811	3236	4404	5176	$1,328,003	$1,573,771	$1,729,897	$1,505,608	$1,620,502
56	2008	1	610286	4904	6675	7844	$1,706,410	$2,385,968	$2,385,968	$2,217,358	$2,217,358
57	2008	1	610811	4904	6675	7844	$1,706,410	$2,159,374	$2,480,489	$2,052,525	$2,296,880
58	2011	2	610811	25718	35004	41138	$6,663,018	$8,540,354	$9,797,399	$8,142,083	$9,143,217
59	2012	2	610911	10800	14699	17276	$3,381,111	$4,280,218	$4,807,232	$4,082,611	$4,486,883
60	2007	1	610811	2200	2994	3519	$1,097,285	$1,261,436	$1,389,444	$1,210,409	$1,304,770
61	2007	1	610811	21505	29269	34399	$5,137,724	$6,709,184	$7,725,527	$6,359,418	$7,150,765
62	2007	1	610811	2790	3797	4463	$1,229,358	$1,447,331	$1,582,168	$1,383,958	$1,480,832
63	1996	1	610287	106900	145496	170996	$21,940,447	$30,012,424	$35,368,675	$28,484,238	$32,861,915
64	2002	1	610675	140000	190547	223942	$29,607,136	$39,985,141	$46,416,197	$37,987,951	$43,093,150
65	2012	1	610249	1349	1836	2158	$913,827	$1,020,212	$1,089,597	$985,304	$1,031,890
66	2003	1	610282	18304	24913	29279	$4,485,739	$5,853,010	$6,710,766	$5,539,775	$6,202,182
67	2000	2	610675	8962	12198	14336	$2,953,432	$2,953,432	$4,213,361	$2,953,432	$3,929,156

Appendix E: PACES Facility Design Initial Construction Cost Estimates

Fac ID	Placed In Service Year	# of Stories	Cat Nbr	Standard Facility Size	Robust Average Facility Size	Robust Large Facility Size	Standard Cost	Robust Average Cost	Robust Large Cost	Flexibility Average Cost	Flexibility Large Cost
68	2005	3	610122	94578	128725	151286	$21,201,621	$29,281,791	$33,823,181	$28,057,621	$31,819,758
69	2008	1	610284	24343	33132	38939	$5,878,467	$7,657,741	$8,779,294	$7,257,716	$8,124,479
70	2008	1	610249	2400	3267	3839	$1,172,643	$1,363,067	$1,486,977	$1,305,589	$1,394,768
71	2010	1	610124	27150	36953	43429	$6,317,913	$8,215,633	$9,456,992	$7,786,136	$8,751,327
72	2002	2	610286	39837	54220	63723	$9,306,413	$12,365,513	$14,233,936	$11,784,491	$13,291,695
73	2001	1	610284	5000	6805	7998	$1,681,610	$2,127,538	$2,358,513	$2,021,830	$2,191,527
74	2010	1	610129	2560	3484	4095	$1,174,941	$1,383,684	$1,507,074	$1,323,957	$1,412,848
75	2001	2	610675	71794	97715	114841	$16,207,694	$21,678,925	$25,021,132	$20,681,715	$23,403,006
76	2004	4	610128	12640	17204	20219	$4,288,056	$5,285,277	$6,018,257	$5,044,579	$5,627,778
77	2014	2	610243	194298	264449	310797	$41,163,740	$55,056,084	$62,687,953	$52,690,561	$58,799,460
78	1997	1	610119	8304	11302	13283	$2,419,204	$3,046,591	$3,509,894	$2,886,445	$3,256,363
79	1998	1	610284	24534	33392	39244	$5,915,058	$7,713,907	$8,843,941	$7,312,753	$8,185,801
80	2011	1	610284	10000	13611	15996	$2,755,159	$3,571,011	$4,042,412	$3,390,145	$3,743,890
81	1997	1	610129	65105	88611	104141	$14,097,129	$18,768,560	$21,928,163	$17,790,780	$20,302,477
82	2002	1	610284	1536	2091	2457	$970,629	$1,105,861	$1,183,047	$1,065,503	$1,118,411
83	2007	1	610243	3800	5172	6078	$1,447,655	$1,728,346	$1,925,672	$1,652,763	$1,794,144
84	2002	1	610281	132430	180244	211833	$27,403,617	$37,126,698	$43,131,218	$35,262,335	$40,051,493
85	2002	1	610249	7548	10273	12074	$2,267,929	$2,838,736	$3,228,648	$2,691,352	$2,991,908
86	2007	1	610129	4993	6796	7987	$1,680,189	$2,124,384	$2,357,363	$2,018,718	$2,190,521
87	2013	1	610913	29354	39952	46954	$6,734,845	$8,772,453	$10,241,553	$8,317,031	$9,488,883
88	2006	1	610249	2805	3818	4487	$1,260,840	$1,483,776	$1,918,734	$1,418,570	$1,738,842

Appendix E: PACES Facility Design Initial Construction Cost Estimates

Fac ID	Placed In Service Year	# of Stories	Cat Nbr	Standard Facility Size	Robust Average Facility Size	Robust Large Facility Size	Standard Cost	Robust Average Cost	Robust Large Cost	Flexibility Average Cost	Flexibility Large Cost
89	2006	1	610811	26630	36245	42597	$6,350,793	$8,256,215	$9,510,882	$7,827,662	$8,796,205
90	2002	3	610811	7090	9650	11341	$2,728,145	$3,292,367	$3,687,798	$3,141,384	$3,446,841
91	2000	1	610913	8000	10888	12797	$2,359,127	$2,962,017	$3,373,272	$2,806,313	$3,125,341
92	2001	1	610127	10325	14053	16516	$2,846,841	$3,671,936	$4,157,470	$3,491,926	$3,858,713
93	2006	1	610811	11066	15061	17701	$3,010,980	$3,878,762	$4,386,586	$3,681,061	$4,069,326
94	2005	1	610811	2369	3224	3789	$1,140,796	$1,325,966	$1,445,362	$1,270,356	$1,356,116
95	2010	1	610284	25855	35190	41357	$6,055,084	$7,851,917	$9,064,815	$7,446,534	$8,392,240
96	2003	1	610915	32490	44221	51971	$7,361,984	$9,591,496	$11,244,438	$9,090,765	$10,403,131
97	1999	1	610121	18119	24661	28983	$4,584,505	$5,943,695	$6,808,747	$5,642,859	$6,310,574
98	2001	3	610249	130447	177545	208661	$29,649,401	$38,920,595	$45,058,838	$37,315,330	$42,413,654
99	2005	2	610243	20000	27221	31992	$5,243,378	$6,794,959	$7,739,130	$6,470,388	$7,210,516
100	2011	1	610243	28500	38790	45588	$6,571,319	$8,560,565	$9,989,408	$8,114,268	$9,256,203
101	2012	1	610127	3000	4083	4799	$1,262,015	$1,505,707	$1,651,733	$1,440,492	$1,546,543
102	2006	1	610913	22500	30624	35991	$5,380,724	$7,004,044	$7,987,844	$6,631,633	$7,390,501
103	2002	1	610112	4480	6098	7166	$1,583,983	$1,928,867	$2,196,877	$1,834,964	$2,043,322
104	2002	1	610112	3773	5135	6035	$1,442,952	$1,723,056	$1,919,265	$1,647,926	$1,788,369
105	1996	1	610243	11476	15619	18357	$3,085,730	$3,970,485	$4,507,747	$3,769,039	$4,179,900
106	1996	1	610127	5336	7263	8535	$1,811,700	$2,264,217	$2,529,016	$2,149,801	$2,347,330
107	1996	1	610144	21026	28617	33633	$5,063,545	$6,589,804	$7,571,304	$6,250,362	$7,013,314
108	1996	2	610243	1483	2018	2372	$1,169,922	$1,312,097	$1,393,280	$1,268,242	$1,321,575
109	1997	1	610311	3674	5001	5877	$1,427,746	$1,681,626	$1,880,494	$1,607,934	$1,752,832

Appendix E: PACES Facility Design Initial Construction Cost Estimates

Fac ID	Placed In Service Year	# of Stories	Cat Nbr	Standard Facility Size	Robust Average Facility Size	Robust Large Facility Size	Standard Cost	Robust Average Cost	Robust Large Cost	Flexibility Average Cost	Flexibility Large Cost
110	1997	3	610913	18489	25164	29575	$5,391,982	$6,922,534	$7,832,655	$6,602,446	$7,313,544
111	2005	1	610285	27856	37913	44558	$6,444,107	$8,390,497	$9,794,121	$7,953,712	$9,075,455
112	2003	1	610144	8692	11830	13904	$2,509,480	$3,152,291	$3,632,617	$2,988,443	$3,366,441
113	2006	1	610122	60162	81884	96234	$12,826,502	$17,040,143	$19,918,383	$16,155,445	$18,459,465
114	1996	1	610913	30191	41091	48293	$7,088,427	$9,225,693	$10,763,875	$8,743,734	$9,956,826
115	2013	1	610122	1109	1509	1774	$856,560	$941,318	$1,007,548	$910,830	$958,251
116	1996	1	610811	2805	3818	4487	$1,231,878	$1,449,709	$1,585,892	$1,386,008	$1,484,167
117	2010	1	610811	119368	162466	190940	$24,277,730	$33,800,595	$39,131,515	$32,105,954	$36,350,205
118	1997	1	610243	7262	9884	11616	$2,212,191	$2,738,036	$3,107,185	$2,603,194	$2,879,712
119	2003	2	610915	24439	33263	39092	$6,240,323	$7,997,987	$7,166,689	$7,622,135	$6,965,075
120	2000	2	610127	6385	8690	10213	$2,353,897	$2,842,240	$3,179,198	$2,716,053	$2,972,539
121	2011	1	610811	45226	61555	72343	$10,159,752	$13,381,026	$16,329,938	$12,672,248	$15,218,546
122	1998	2	610249	44742	60896	71569	$10,489,063	$13,685,140	$15,794,460	$13,047,500	$14,760,338
123	1999	1	610144	4797	6529	7673	$1,651,096	$2,062,269	$2,301,830	$1,962,794	$2,139,656
124	2005	1	610913	2000	2722	3199	$1,046,049	$1,215,803	$1,319,379	$1,168,472	$1,240,022
Extra 125	2011	1	610243	4667	6352	7465	$1,641,281	$1,994,053	$2,260,518	$1,892,168	$1,892,168
Extra 126	2007	1	610811	4897	6665	7833	$1,678,914	$2,102,142	$2,335,533	$1,993,294	$1,993,294
Extra 127	2006	1	610127	1620	2205	2591	$991,122	$1,122,027	$1,198,965	$1,079,281	$1,079,281
Extra 128	2007	1	610811	2200	2994	3519	$1,118,231	$1,279,754	$1,406,882	$1,226,487	$1,226,487

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Fac ID	Placed In Service Year	# of Stories	Cat Nbr	Standard Facility Size	Robust Average Facility Size	Robust Large Facility Size	Standard Cost	Robust Average Cost	Robust Large Cost	Flexibility Average Cost	Flexibility Large Cost
Extra 129	2005	1	610142	4840	6587	7742	$1,671,690	$2,080,373	$2,320,357	$1,975,843	$1,975,843
Extra 130	2009	1	610249	4330	5893	6926	$1,558,462	$1,892,741	$2,154,343	$1,798,065	$1,798,065
Extra 131	2007	1	610127	2200	2994	3519	$1,118,231	$1,279,754	$1,406,882	$1,226,487	$1,226,487
Extra 132	2009	1	610129	4329	5892	6925	$1,558,259	$1,892,696	$2,154,299	$1,797,868	$1,797,868
Extra 133	2006	1	610711	3500	4764	5599	$1,404,090	$1,660,155	$1,832,677	$1,585,901	$1,585,901
Extra 134	2008	1	610243	2475	3369	3959	$1,179,139	$1,383,692	$1,485,922	$1,323,836	$1,323,836
Extra 135	2005	1	610127	4184	5695	6693	$1,536,028	$1,867,534	$2,121,795	$1,774,973	$1,774,973
Extra 136	2006	1	610121	1920	2613	3071	$1,055,066	$1,202,414	$1,312,810	$1,154,407	$1,154,407
Extra 137	2008	2	610127	5654	7695	9044	$2,181,637	$2,595,881	$2,871,436	$2,476,414	$2,476,414
Extra 138	2009	2	610284	2160	2940	3455	$1,365,444	$1,538,215	$1,666,114	$1,478,118	$1,478,118
Extra 139	2009	1	610281	4200	5716	6718	$1,540,821	$1,869,769	$2,124,099	$1,776,952	$1,776,952
Extra 140	2006	1	610249	4000	5444	6398	$1,490,244	$1,805,256	$1,999,502	$1,715,996	$1,715,996
Extra 141	2005	3	610249	4560	6206	7294	$2,076,675	$2,490,153	$2,713,752	$2,378,984	$2,378,984

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Fac ID	Placed In Service Year	# of Stories	Cat Nbr	Standard Facility Size	Robust Average Facility Size	Robust Large Facility Size	Standard Cost	Robust Average Cost	Robust Large Cost	Flexibility Average Cost	Flexibility Large Cost
Extra 142	2007	1	610285	5000	6805	7998	$1,693,556	$2,136,761	$2,363,067	$2,026,416	$2,026,416
Extra 143	2007	1	610284	4447	6053	7113	$1,594,768	$1,931,920	$2,197,777	$1,834,447	$1,834,447
Extra 144	2007	1	610811	2200	2994	3519	$1,118,231	$1,279,754	$1,406,882	$1,226,487	$1,226,487
Extra 145	2007	1	610811	2790	3797	4463	$1,248,836	$1,463,869	$1,596,392	$1,397,717	$1,397,717
Extra 146	2005	1	610913	3575	4866	5719	$1,415,871	$1,675,747	$1,869,987	$1,600,381	$1,600,381
Extra 147	2007	1	610811	4280	5825	6846	$1,551,932	$1,882,438	$2,141,083	$1,788,512	$1,788,512
Extra 148	2003	1	610144	3654	4973	5845	$1,427,208	$1,690,011	$1,885,143	$1,613,458	$1,613,458
Extra 149	2000	1	610144	3756	5112	6008	$1,457,613	$1,732,188	$1,926,127	$1,653,955	$1,653,955
Extra 150	2003	1	610243	3604	4905	5765	$1,420,415	$1,679,865	$1,876,362	$1,604,070	$1,604,070
Extra 151	2003	2	610127	3299	4490	5277	$1,622,213	$1,878,002	$2,039,798	$1,797,739	$1,797,739
Extra 152	2004	1	610144	1700	2314	2719	$1,018,351	$1,138,722	$1,235,065	$1,094,634	$1,094,634
Extra 153	2003	1	610144	3454	4701	5525	$1,397,336	$1,644,876	$1,821,227	$1,571,468	$1,571,468
Extra 154	1998	2	610284	4890	6656	7822	$1,958,404	$2,385,496	$2,619,864	$2,278,031	$2,278,031

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Fac ID	Placed In Service Year	# of Stories	Cat Nbr	Standard Facility Size	Robust Average Facility Size	Robust Large Facility Size	Standard Cost	Robust Average Cost	Robust Large Cost	Flexibility Average Cost	Flexibility Large Cost
Extra 155	1998	1	610243	3100	4219	4959	$1,316,108	$1,542,907	$1,688,147	$1,472,768	$1,472,768
Extra 156	1999	1	610711	6000	8166	9598	$1,905,659	$2,405,902	$2,675,158	$2,285,109	$2,285,109
Extra 157	1997	1	610127	2132	2902	3410	$1,106,887	$1,266,762	$1,388,696	$1,214,635	$1,214,635
Extra 158	1997	2	610811	3400	4628	5439	$1,655,583	$1,899,564	$2,086,696	$1,817,623	$1,817,623
Extra 159	1996	1	610144	3266	4445	5224	$1,349,677	$1,594,602	$1,749,508	$1,522,935	$1,522,935
Extra 160	1999	1	610284	3600	4900	5759	$1,419,174	$1,679,451	$1,875,685	$1,603,695	$1,603,695
Extra 161	2001	1	610144	18923	25755	30269	$4,572,878	$5,978,870	$6,866,330	$5,642,414	$5,642,414
Extra 162	2001	2	610127	15709	21381	25128	$4,265,100	$5,421,772	$6,160,620	$5,143,022	$5,143,022
Extra 163	1999	2	610913	8354	11370	13363	$2,731,652	$3,355,870	$3,824,694	$3,184,918	$3,184,918
Extra 164	1999	2	610243	7992	10878	12784	$2,648,578	$3,247,497	$3,713,212	$3,081,779	$3,081,779
Extra 165	1997	1	610119	24737	33668	39569	$5,782,312	$7,506,354	$8,601,501	$7,096,845	$7,096,845
Extra 166	2005	4	610811	412687	561688	660129	$78,110,156	$104,941,845	$122,259,479	$100,196,179	$100,196,179
Extra 167	2007	2	610128	40155	54653	64231	$8,965,379	$11,871,127	$13,640,141	$11,259,902	$11,259,902

Appendix E: PACES Facility Design Initial Construction Cost Estimates

Fac ID	Placed In Service Year	# of Stories	Cat Nbr	Standard Facility Size	Robust Average Facility Size	Robust Large Facility Size	Standard Cost	Robust Average Cost	Robust Large Cost	Flexibility Average Cost	Flexibility Large Cost
Extra 168	2008	2	610285	38534	52447	61639	$8,647,961	$11,472,413	$13,178,077	$10,875,816	$10,875,816
Extra 169	2008	1	610243	34175	46514	54666	$7,586,524	$10,044,984	$11,591,839	$9,492,752	$9,492,752
Extra 170	2007	3	610127	52788	71847	84439	$11,800,286	$15,447,568	$17,826,567	$14,690,058	$14,690,058
Extra 171	2005	2	610243	29396	40009	47021	$6,956,059	$8,946,040	$10,443,642	$8,487,591	$8,487,591
Extra 172	2009	5	610284	47611	64801	76158	$11,515,575	$14,866,089	$17,060,174	$14,110,580	$14,110,580
Extra 173	2007	1	610127	26900	36612	43029	$6,202,689	$8,057,094	$9,272,381	$7,609,306	$7,609,306
Extra 174	2004	1	610119	63151	85952	101016	$13,193,459	$17,543,004	$20,519,968	$16,577,916	$16,577,916
Extra 175	2000	2	610281	27028	36786	43234	$6,511,588	$8,336,677	$9,627,079	$7,909,460	$7,909,460
Extra 176	2003	2	610249	27738	37753	44369	$6,640,210	$8,509,401	$9,977,154	$8,079,824	$8,079,824
Extra 177	2002	3	610284	103360	140678	165333	$21,351,737	$29,680,476	$34,076,090	$28,324,888	$28,324,888
Extra 178	2002	1	610122	36161	49217	57843	$7,962,201	$10,575,031	$12,175,669	$9,973,404	$9,973,404
Extra 179	2000	2	610811	35469	48275	56736	$8,068,885	$10,685,752	$12,250,381	$10,132,707	$10,132,707
Extra 180	1996	2	610243	59942	81584	95882	$12,824,843	$16,930,113	$19,739,081	$16,080,280	$16,080,280

Appendix E: PACES Facility Design Initial Construction Cost Estimates

Fac ID	Placed In Service Year	# of Stories	Cat Nbr	Standard Facility Size	Robust Average Facility Size	Robust Large Facility Size	Standard Cost	Robust Average Cost	Robust Large Cost	Flexibility Average Cost	Flexibility Large Cost
Extra 181	1997	2	610249	38300	52128	61264	$8,598,327	$11,407,740	$13,100,475	$10,811,463	$10,811,463
Extra 182	1998	1	610243	33300	45323	53266	$7,429,918	$9,813,745	$11,338,049	$9,276,948	$9,276,948
Extra 183	1997	1	610284	28441	38710	45494	$6,500,902	$8,447,132	$9,850,647	$7,981,808	$7,981,808
Extra 184	1999	3	610249	103624	141038	165756	$21,386,791	$29,744,474	$34,153,783	$28,385,016	$28,385,016
Extra 185	1996	1	610243	347371	472790	555650	$66,472,856	$89,793,944	$104,684,360	$84,920,503	$84,920,503

Appendix F: PACES Addition Costs Estimates

Facility ID	Project Year	CATCODE	Size	Assumed Size	Standard Addition Cost	Flexible Addition Cost
10	2009	843316		1700	$1,020,109.73	$259,307.95
11	2004	724417		1529	$1,217,517.31	$297,472.24
13	2004	610286		237.216	$631,239.97	$103,601.18
14	2002	610711	279		$641,206.73	$109,596.11
17	2010	610144	600		$746,465.19	$165,074.09
18	2010	610285	148		$941,214.54	$136,609.46
18	2014	141753		652	$1,103,677.94	$234,463.64
22	2002	141753		1013	$860,957.51	$203,787.00
36	2011	131111		1641	$995,564.00	$254,841.93
38	2012	141461	1954		$1,316,193.25	$334,005.26
51	2006	171443	1000		$841,778.49	$202,649.33
63	2002	750423	4000		$1,492,803.17	$412,874.73
68	2005	610284		1162	$1,255,100.82	$282,794.62
68	2007	750371		452	$1,037,031.88	$185,927.06
72	2010	740270	3000		$1,549,436.87	$416,264.17
76	2009	730835	500		$1,169,963.73	$215,918.47
84	2007	730841	1600		$987,816.43	$251,860.21
109	2010	610311	500		$704,538.20	$136,544.42
112	2012	610144		74	$620,543.19	$97,998.32
112	2012	610144		5265	$1,757,869.02	$486,407.52
124	2011	610913	2000		$1,069,029.54	$280,800.40
Extra 139	2009	610281		2547	$1,193,664.09	$318,846.44
Extra 141	2006	750371	900		$1,174,217.58	$250,162.04
Extra 141	2011	610249		1360	$1,311,449.38	$304,757.46
Extra 141	2014	610249		168	$941,214.54	$136,609.46
Extra 143	2012	610284		1412	$949,313.10	$237,503.82
Extra 148	2009	610144	1700		$1,020,109.73	$259,307.95
Extra 155	1999	610243	3500		$1,406,502.84	$383,202.87
Extra 159	2010	125977	1900		$1,054,272.33	$273,699.85
Extra 160	2006	610284	2800		$1,252,211.03	$335,252.34
Extra 176	2003	610249		1615	$1,241,291.12	$305,201.66
Extra 177	2006	610284	150		$941,214.54	$136,609.46
Extra 183	2006	610284	2500		$1,184,809.24	$315,844.68

Appendix G: PACES Modification Costs Estimates

Sample #	Size	System	Size	Cost
2	Mean	COMM	6940	$130,951.13
3	Mean	COMM	113864	$907,803.97
14	Mean	COMM	4000	$113,330.63
15	Mean	COMM	168490	$1,296,802.98
18	Mean	COMM	7265	$133,970.91
26	Mean	COMM	3844	$112,067.71
28	Mean	COMM	3995	$113,313.36
29	Mean	COMM	2347	$103,445.82
31	Mean	COMM	4387	$116,199.00
38	Mean	COMM	2123	$102,489.38
42	Mean	COMM	3258	$108,156.60
45	Mean	COMM	6686	$129,272.38
58	Mean	COMM	25718	$257,540.86
59	Mean	COMM	10800	$155,207.06
64	Mean	COMM	140000	$1,096,699.56
68	Mean	COMM	94578	$765,409.67
69	Mean	COMM	24343	$249,111.99
73	Mean	COMM	5000	$120,554.48
75	Mean	COMM	71794	$598,501.36
76	Mean	COMM	12640	$166,211.52
78	Mean	COMM	8304	$139,816.03
84	Mean	COMM	132430	$1,040,406.62

Sample #	Size	System	Size	Cost
7	Mean	Plumbing	24196	$204,786.45
11	Mean	Plumbing	14976	$164,797.15
14	Mean	Plumbing	4000	$96,600.16
15	Mean	Plumbing	168490	$914,442.19
22	Mean	Plumbing	10320	$123,088.91
31	Mean	Plumbing	4387	$97,630.88
45	Mean	Plumbing	6686	$111,391.99
64	Mean	Plumbing	140000	$777,195.84
66	Mean	Plumbing	18304	$177,786.76
68	Mean	Plumbing	94578	$547,433.06
69	Mean	Plumbing	24343	$205,174.39
70	Mean	Plumbing	2400	$91,517.30
76	Mean	Plumbing	12640	$153,410.73
84	Mean	Plumbing	132430	$736,800.43
88	Mean	Plumbing	2805	$92,594.80
90	Mean	Plumbing	7090	$112,469.43
98	Mean	Plumbing	130447	$729,732.53
109	Mean	Plumbing	3674	$95,731.00
114	Mean	Plumbing	30191	$231,513.06
120	Mean	Plumbing	6385	$106,556.43
122	Mean	Plumbing	44742	$308,566.11
124	Mean	Plumbing	2000	$90,450.21

Appendix G: PACES Modification Costs Estimates

Sample #	Size	System	Size	Cost
86	Mean	COMM	4993	$137,649.00
90	Mean	COMM	7090	$131,594.97
98	Mean	COMM	130447	$1,027,971.26
99	Mean	COMM	20000	$211,391.74
105	Mean	COMM	11476	$159,833.87
107	Mean	COMM	21026	$226,961.17
108	Mean	COMM	1483	$98,839.49
119	Mean	COMM	24439	$249,527.06
120	Mean	COMM	6385	$126,472.91
122	Mean	COMM	44742	$386,717.98
Extra 132	Mean	COMM	4329	$117,201.12
Extra 135	Mean	COMM	4184	$116,576.31
Extra 137	Mean	COMM	5654	$126,007.90
Extra 141	Mean	COMM	4560	$120,405.54
Extra 143	Mean	COMM	4447	$118,959.61
Extra 148	Mean	COMM	3654	$113,657.88
Extra 166	Mean	COMM	412687	$3,148,459.18
Extra 167	Mean	COMM	40155	$363,330.70
Extra 168	Mean	COMM	38534	$353,164.67
Extra 172	Mean	COMM	47611	$421,086.69
Extra 173	Mean	COMM	26900	$269,487.96
Extra 175	Mean	COMM	27028	$270,988.96

Sample #	Size	System	Size	Cost
Extra 127	Mean	Plumbing	1620	$91,364.57
Extra 135	Mean	Plumbing	4184	$99,183.77
Extra 137	Mean	Plumbing	5654	$106,251.39
Extra 141	Mean	Plumbing	4560	$100,209.39
Extra 143	Mean	Plumbing	4447	$99,896.03
Extra 152	Mean	Plumbing	1700	$91,581.65
Extra 163	Mean	Plumbing	8354	$119,171.06
Extra 167	Mean	Plumbing	40155	$279,731.68
Extra 168	Mean	Plumbing	38534	$274,095.25
Extra 170	Mean	Plumbing	52788	$350,751.38
Extra 172	Mean	Plumbing	47611	$325,262.89
Extra 173	Mean	Plumbing	26900	$218,845.26
Extra 175	Mean	Plumbing	27028	$219,192.08
Extra 177	Mean	Plumbing	103360	$611,846.12
Extra 179	Mean	Plumbing	35469	$263,449.26
Extra 183	Mean	Plumbing	28441	$228,359.97
7	Median	Plumbing	24196	$135,391.57
11	Median	Plumbing	14976	$119,348.85
14	Median	Plumbing	4000	$88,670.67
15	Median	Plumbing	168490	$356,274.96
22	Median	Plumbing	10320	$94,288.78
31	Median	Plumbing	4387	$89,014.72

Appendix G: PACES Modification Costs Estimates

Sample #	Size	System	Size	Cost
Extra 176	Mean	COMM	27738	$275,301.87
Extra 177	Mean	COMM	103360	$841,819.97
Extra 178	Mean	COMM	36161	$338,700.76
Extra 179	Mean	COMM	35469	$333,298.22
Extra 180	Mean	COMM	59942	$511,312.15
Extra 184	Mean	COMM	103624	$844,411.83
2	Median	COMM	6940	$107,713.51
3	Median	COMM	113864	$441,747.56
14	Median	COMM	4000	$100,270.35
15	Median	COMM	168490	$630,402.86
18	Median	COMM	7265	$108,343.62
26	Median	COMM	3844	$99,965.90
28	Median	COMM	3995	$100,260.35
29	Median	COMM	2347	$97,059.93
31	Median	COMM	4387	$101,020.42
38	Median	COMM	2123	$96,625.33
42	Median	COMM	3258	$98,831.95
45	Median	COMM	6686	$107,221.22
58	Median	COMM	25718	$160,744.75
59	Median	COMM	10800	$118,135.00
64	Median	COMM	140000	$525,651.65
68	Median	COMM	94578	$372,480.07

Sample #	Size	System	Size	Cost
45	Median	Plumbing	6686	$91,059.67
64	Median	Plumbing	140000	$315,881.64
66	Median	Plumbing	18304	$125,303.79
68	Median	Plumbing	94578	$236,255.88
69	Median	Plumbing	24343	$135,519.48
70	Median	Plumbing	2400	$87,249.43
76	Median	Plumbing	12640	$116,673.19
84	Median	Plumbing	132430	$301,625.84
88	Median	Plumbing	2805	$87,608.82
90	Median	Plumbing	7090	$91,419.34
98	Median	Plumbing	130447	$299,262.80
109	Median	Plumbing	3674	$88,382.14
114	Median	Plumbing	30191	$141,318.70
120	Median	Plumbing	6385	$90,793.89
122	Median	Plumbing	44742	$164,629.72
124	Median	Plumbing	2000	$86,894.08
Extra 127	Median	Plumbing	1620	$88,421.47
Extra 135	Median	Plumbing	4184	$90,750.96
Extra 137	Median	Plumbing	5654	$92,085.60
Extra 141	Median	Plumbing	4560	$91,091.22
Extra 143	Median	Plumbing	4447	$90,988.92
Extra 152	Median	Plumbing	1700	$88,492.55

Appendix G: PACES Modification Costs Estimates

Sample #	Size	System	Size	Cost
69	Median	COMM	24343	$156,259.81
73	Median	COMM	5000	$102,209.53
75	Median	COMM	71794	$306,738.11
76	Median	COMM	12640	$123,737.88
78	Median	COMM	8304	$111,772.52
84	Median	COMM	132430	$502,200.67
86	Median	COMM	4993	$102,196.11
90	Median	COMM	7090	$108,005.52
98	Median	COMM	130447	$496,693.65
99	Median	COMM	20000	$143,176.52
105	Median	COMM	11476	$121,480.76
107	Median	COMM	21026	$146,090.15
108	Median	COMM	1483	$95,386.58
119	Median	COMM	24439	$156,449.82
120	Median	COMM	6385	$106,638.08
122	Median	COMM	44742	$214,241.45
Extra 132	Median	COMM	4329	$103,080.17
Extra 135	Median	COMM	4184	$102,796.58
Extra 137	Median	COMM	5654	$107,488.31
Extra 141	Median	COMM	4560	$103,543.94
Extra 143	Median	COMM	4447	$103,314.46
Extra 148	Median	COMM	3654	$101,746.22

Sample #	Size	System	Size	Cost
Extra 163	Median	Plumbing	8354	$94,538.45
Extra 167	Median	Plumbing	40155	$158,750.28
Extra 168	Median	Plumbing	38534	$157,277.13
Extra 170	Median	Plumbing	52788	$179,688.97
Extra 172	Median	Plumbing	47611	$171,383.05
Extra 173	Median	Plumbing	26900	$140,767.07
Extra 175	Median	Plumbing	27028	$140,883.35
Extra 177	Median	Plumbing	103360	$254,332.52
Extra 179	Median	Plumbing	35469	$154,492.56
Extra 183	Median	Plumbing	28441	$142,165.06

Sample #	Size	System	Size	Cost
3	Mean	HVAC	113864	$2,153,797.13
14	Mean	HVAC	4000	$238,030.89
18	Mean	HVAC	7265	$329,567.52
26	Mean	HVAC	3844	$236,385.52
29	Mean	HVAC	2347	$225,663.73
31	Mean	HVAC	4387	$255,878.25
42	Mean	HVAC	3258	$231,006.61
44	Mean	HVAC	5193	$259,410.55
45	Mean	HVAC	6686	$284,735.89
66	Mean	HVAC	18304	$491,006.56
68	Mean	HVAC	94578	$1,891,187.16

Appendix G: PACES Modification Costs Estimates

Sample #	Size	System	Size	Cost
Extra 166	Median	COMM	412687	$1,472,832.03
Extra 167	Median	COMM	40155	$204,743.26
Extra 168	Median	COMM	38534	$199,751.47
Extra 172	Median	COMM	47611	$226,099.83
Extra 173	Median	COMM	26900	$167,164.62
Extra 175	Median	COMM	27028	$167,415.06
Extra 176	Median	COMM	27738	$168,824.24
Extra 177	Median	COMM	103360	$415,961.46
Extra 178	Median	COMM	36161	$194,438.93
Extra 179	Median	COMM	35469	$193,067.02
Extra 180	Median	COMM	59942	$270,996.95
Extra 184	Median	COMM	103624	$416,481.98

Sample #	Size	System	Size	Cost
3	Mean	Electric	113864	$1,147,370.67
11	Mean	Electric	14976	$225,999.33
14	Mean	Electric	4000	$107,290.17
18	Mean	Electric	7265	$124,661.67
28	Mean	Electric	3995	$107,274.33
29	Mean	Electric	2347	$97,994.60
31	Mean	Electric	4387	$108,803.17
44	Mean	Electric	5193	$112,770.57
45	Mean	Electric	6686	$120,169.41

Sample #	Size	System	Size	Cost
69	Mean	HVAC	24343	$595,323.37
73	Mean	HVAC	5000	$258,139.47
75	Mean	HVAC	71794	$1,462,552.54
76	Mean	HVAC	12640	$453,321.84
78	Mean	HVAC	8304	$313,457.00
84	Mean	HVAC	132430	$2,474,093.54
90	Mean	HVAC	7090	$326,716.98
98	Mean	HVAC	130447	$2,529,683.08
99	Mean	HVAC	20000	$543,087.77
110	Mean	HVAC	18489	$539,545.65
119	Mean	HVAC	24439	$630,233.06
120	Mean	HVAC	6385	$302,052.24
122	Mean	HVAC	44742	$974,781.33
Extra 132	Mean	HVAC	4329	$245,836.35
Extra 134	Mean	HVAC	2475	$211,567.99
Extra 137	Mean	HVAC	5654	$288,302.47
Extra 142	Mean	HVAC	5000	$264,194.58
Extra 143	Mean	HVAC	4447	$262,299.54
Extra 152	Mean	HVAC	1700	$205,760.29
Extra 163	Mean	HVAC	8354	$342,663.23
Extra 167	Mean	HVAC	40155	$915,968.33
Extra 168	Mean	HVAC	38534	$889,087.47

Appendix G: PACES Modification Costs Estimates

Sample #	Size	System	Size	Cost
59	Mean	Electric	10800	$150,129.74
64	Mean	Electric	140000	$1,403,061.24
68	Mean	Electric	94578	$980,898.59
69	Mean	Electric	24343	$322,636.87
75	Mean	Electric	71794	$762,114.72
76	Mean	Electric	12640	$213,419.73
78	Mean	Electric	8304	$130,136.64
84	Mean	Electric	132430	$1,263,746.70
90	Mean	Electric	7090	$122,348.07
92	Mean	Electric	10325	$139,821.21
98	Mean	Electric	130447	$1,252,942.76
99	Mean	Electric	20000	$251,730.19
105	Mean	Electric	11476	$176,607.00
107	Mean	Electric	21026	$258,336.01
108	Mean	Electric	1483	$94,620.34
119	Mean	Electric	24439	$333,417.76
122	Mean	Electric	44742	$562,688.95
Extra 134	Mean	Electric	2475	$100,624.86
Extra 137	Mean	Electric	5654	$118,028.78
Extra 141	Mean	Electric	4560	$111,842.73
Extra 142	Mean	Electric	5000	$114,430.90
Extra 143	Mean	Electric	4447	$111,382.84

Sample #	Size	System	Size	Cost
Extra 170	Mean	HVAC	52788	$1,165,095.68
Extra 172	Mean	HVAC	47611	$1,130,956.24
Extra 175	Mean	HVAC	27028	$694,819.34
Extra 176	Mean	HVAC	27738	$700,341.86
Extra 177	Mean	HVAC	103360	$2,094,650.95
Extra 178	Mean	HVAC	36161	$809,430.13
Extra 179	Mean	HVAC	35469	$835,222.04
Extra 183	Mean	HVAC	28441	$684,519.05
3	Median	HVAC	113864	$593,021.95
14	Median	HVAC	4000	$168,090.21
18	Median	HVAC	7265	$194,872.18
26	Median	HVAC	3844	$193,005.00
29	Median	HVAC	2347	$168,630.86
31	Median	HVAC	4387	$168,669.16
42	Median	HVAC	3258	$166,950.34
44	Median	HVAC	5193	$167,331.07
45	Median	HVAC	6686	$184,775.20
66	Median	HVAC	18304	$219,050.98
68	Median	HVAC	94578	$535,334.88
69	Median	HVAC	24343	$242,912.19
73	Median	HVAC	5000	$167,042.89
75	Median	HVAC	71794	$430,541.29

Appendix G: PACES Modification Costs Estimates

Sample #	Size	System	Size	Cost
Extra 146	Mean	Electric	3575	$106,461.63
Extra 149	Mean	Electric	3756	$108,019.69
Extra 152	Mean	Electric	1700	$97,527.70
Extra 163	Mean	Electric	8354	$133,145.02
Extra 166	Mean	Electric	412687	$3,534,007.64
Extra 167	Mean	Electric	40155	$435,691.41
Extra 168	Mean	Electric	38534	$427,359.08
Extra 170	Mean	Electric	52788	$623,049.86
Extra 172	Mean	Electric	47611	$590,828.18
Extra 173	Mean	Electric	26900	$353,347.30
Extra 175	Mean	Electric	27028	$353,857.17
Extra 176	Mean	Electric	27738	$357,911.68
Extra 177	Mean	Electric	103360	$1,055,479.24
Extra 178	Mean	Electric	36161	$414,703.33
Extra 179	Mean	Electric	35469	$410,497.19
Extra 183	Mean	Electric	28441	$369,624.81
Extra 184	Mean	Electric	103624	$1,057,975.03
3	Median	Electric	113864	$825,517.97
11	Median	Electric	14976	$190,376.10
14	Median	Electric	4000	$97,353.08
18	Median	Electric	7265	$107,144.59
28	Median	Electric	3995	$97,345.40

Sample #	Size	System	Size	Cost
76	Median	HVAC	12640	$208,503.11
78	Median	HVAC	8304	$186,838.32
84	Median	HVAC	132430	$658,895.61
90	Median	HVAC	7090	$194,594.37
98	Median	HVAC	130447	$675,674.00
99	Median	HVAC	20000	$226,307.68
110	Median	HVAC	18489	$230,657.34
119	Median	HVAC	24439	$252,081.11
120	Median	HVAC	6385	$172,618.26
122	Median	HVAC	44742	$326,156.68
Extra 132	Median	HVAC	4329	$172,535.41
Extra 134	Median	HVAC	2475	$166,793.36
Extra 137	Median	HVAC	5654	$175,484.67
Extra 142	Median	HVAC	5000	$170,955.70
Extra 143	Median	HVAC	4447	$172,716.98
Extra 152	Median	HVAC	1700	$165,471.82
Extra 163	Median	HVAC	8354	$195,400.19
Extra 167	Median	HVAC	40155	$327,031.89
Extra 168	Median	HVAC	38534	$309,240.04
Extra 170	Median	HVAC	52788	$370,081.31
Extra 172	Median	HVAC	47611	$373,551.32
Extra 175	Median	HVAC	27028	$277,192.07

Appendix G: PACES Modification Costs Estimates

Sample #	Size	System	Size	Cost
29	Median	Electric	2347	$93,822.43
31	Median	Electric	4387	$98,179.64
44	Median	Electric	5193	$100,713.39
45	Median	Electric	6686	$105,311.14
59	Median	Electric	10800	$124,325.63
64	Median	Electric	140000	$987,429.72
68	Median	Electric	94578	$711,864.52
69	Median	Electric	24343	$261,269.33
75	Median	Electric	71794	$554,387.74
76	Median	Electric	12640	$182,347.98
78	Median	Electric	8304	$109,361.05
84	Median	Electric	132430	$894,846.30
90	Median	Electric	7090	$106,175.82
92	Median	Electric	10325	$131,643.00
98	Median	Electric	130447	$890,014.90
99	Median	Electric	20000	$202,800.41
105	Median	Electric	11476	$125,769.02
107	Median	Electric	21026	$207,425.75
108	Median	Electric	1483	$91,982.58
119	Median	Electric	24439	$272,474.59
122	Median	Electric	44742	$442,160.73
Extra 134	Median	Electric	2475	$96,127.61

Sample #	Size	System	Size	Cost
Extra 176	Median	HVAC	27738	$278,169.35
Extra 177	Median	HVAC	103360	$579,252.08
Extra 178	Median	HVAC	36161	$299,458.95
Extra 179	Median	HVAC	35469	$305,165.02
Extra 183	Median	HVAC	28441	$273,333.17

Appendix G: PACES Modification Costs Estimates

Sample #	Size	System	Size	Cost
Extra 137	Median	Electric	5654	$103,891.17
Extra 141	Median	Electric	4560	$100,673.57
Extra 142	Median	Electric	5000	$102,466.10
Extra 143	Median	Electric	4447	$100,424.53
Extra 146	Median	Electric	3575	$98,525.65
Extra 149	Median	Electric	3756	$98,921.45
Extra 152	Median	Electric	1700	$94,439.65
Extra 163	Median	Electric	8354	$111,830.48
Extra 166	Median	Electric	412687	$2,277,593.27
Extra 167	Median	Electric	40155	$324,650.81
Extra 168	Median	Electric	38534	$320,207.26
Extra 170	Median	Electric	52788	$482,262.94
Extra 172	Median	Electric	47611	$529,209.00
Extra 173	Median	Electric	26900	$285,988.58
Extra 175	Median	Electric	27028	$286,267.98
Extra 176	Median	Electric	27738	$287,815.04
Extra 177	Median	Electric	103360	$752,970.31
Extra 178	Median	Electric	36161	$311,776.86
Extra 179	Median	Electric	35469	$310,567.33
Extra 183	Median	Electric	28441	$290,178.73

Appendix H: LCC Distribution Fit Results

Design	Size	Adj R^2	N	Overall p-value	Parameter Estimates Term	Estimate	p-value
Standard	All	0.9977	123	<.0001		793066.85	<.0001
					(Size)	204.49704	<.0001
Flexible	Average	0.9987	123	<.0001		748729.11	<.0001
					(Size)	267.12747	<.0001
	Large	0.9985	123	<.0001		781230.04	<.0001
					(Size)	302.58149	<.0001
Robust	Average	0.9989	123	<.0001		800109.8	<.0001
					(Avg Size)	205.69462	<.0001
	Large	0.9988	123	<.0001		860659.69	<.0001
					(Large Size)	202.42382	<.0001

Design	Size	Adj R^2	N	Overall p-value	Parameter Estimates Term	Estimate	p-value
Standard	1 Story & <=2000 sq-ft	0.9987	10	<.0001		587770.49	<.0001
					(Size)	255.30046	<.0001
					$(Size)^2$	-0.034252	0.0007
	>1 Story & <=2000 sq-ft	0.9983	10	<.0001		762491.78	<.0001
					(Size)	294.13388	<.0001
					$(Size)^2$	-0.028977	0.0149
Flexible	1 Story & <=2000 sq-ft	0.9941	10	<.0001		102596.39	<.0001
					(Size)	96.037325	<.0001
					$(Size)^2$	-0.029364	0.0006
	>1 Story & <=2000 sq-ft	0.9963	10	<.0001		110923.57	<.0001
					(Size)	119.31587	<.0001
					$(Size)^2$	-0.022339	0.0023
	>2000 & <=90000 sq-ft	0.9895	109	<.0001		242176.45	<.0001
					(Size)	47.418008	<.0001
	>90000 sq-ft	0.9869	14	<.0001		1449143.5	<.0001
					(Size)	32.733007	<.0001

Appendix H: LCC Distribution Fit Results

System	Size	Adj R^2	N	Overall p-value	Parameter Estimates Term	Estimate	p-value
Comm	Median	0.9991	31	<.0001		8540.873	<.0001
					(Size)	3.1166	<.0001
	Mean	0.9996	32	<.0001		80771.311	<.0001
					(Size)	7.2270	<.0001
Electrical	Median	0.9928	26	<.0001		76229.68	<.0001
					(Size)	6.4750	<.0001
	Mean	0.9965	26	<.0001		72737.512	<.0001
					(Size)	9.3469	<.0001
HVAC	Median 1 Story	0.9975	12	<.0001		154855.44	<.0001
					(Size)	3.8176	<.0001
	Median > 1 Story	0.9981	12	<.0001		156490.77	<.0001
					(Size)	3.9482	<.0001
	Mean 1 Story	1.0000	12	<.0001		171399.41	<.0001
					(Size)	17.3976	<.0001
	Mean > 1 Story	0.9996	12	<.0001		196252.41	<.0001
					(Size)	17.8398	<.0001
Plumbing	Median	0.9947	22	<.0001		86414.902	<.0001
					(Size)	1.6289	<.0001
	Mean	0.9997	22	<.0001		80642.564	<.0001
					(Size)	4.9662	<.0001

Appendix H: LCC Distribution Fit Results

	Size	Adj R^2	N	Overall p-value	Parameter Estimates				
					Term	Estimate	Std Error	t Ratio	p-value
Year 1	**All**	0.9925	8	<.0001		19236.529	2430.943	7.910	0.0002
					(Size)	12.214	0.402	30.410	<.0001
Year 2	**All**	0.9926	18	<.0001		27991.918	2534.032	11.050	<.0001
					(Size)	10.580	0.222	47.640	<.0001
Year 3	**All**	0.9854	30	<.0001		23453.037	3982.868	5.890	<.0001
					(Size)	11.464	0.259	44.200	<.0001
Year 4	**<= 9000 sq-ft**	0.9713	28	<.0001		26712.066	1546.526	17.270	<.0001
					(Size)	10.192	0.337	30.270	<.0001
	> 9000 sq-ft	0.9961	34	<.0001		67787.387	12855.390	5.270	<.0001
					(Size)	9.611	0.105	91.500	<.0001
Year 5	**<= 9000 sq-ft**	0.9602	33	<.0001		22713.059	191.772	11.830	<.0001
					(Size)	11.239	0.404	27.790	<.0001
	> 9000 sq-ft	0.9940	54	<.0001		78682.760	11027.390	7.140	<.0001
					(Size)	9.610	0.102	93.940	<.0001
Year 6	**<= 9000 sq-ft**	0.9607	36	<.0001		22748.417	1841.790	12.350	<.0001
					(Size)	11.277	0.385	29.260	<.0001
	> 9000 sq-ft	0.9940	54	<.0001		78682.760	11027.390	7.140	<.0001
					(Size)	9.610	0.102	93.940	<.0001
Year 7	**<= 9000 sq-ft**	0.9669	45	<.0001		22981.580	1504.621	15.270	<.0001
					(Size)	11.305	0.315	35.870	<.0001
	> 9000 sq-ft	0.9941	63	<.0001		72239.718	9459.282	7.640	<.0001
					(Size)	9.639	0.094	102.390	<.0001
Year 8	**<= 9000 sq-ft**	0.9779	57	<.0001		22075.001	1149.657	19.200	<.0001
					(Size)	11.576	0.233	49.740	<.0001
	> 9000 sq-ft	0.9903	75	<.0001		65505.380	11734.470	5.580	<.0001
					(Size)	9.887	0.114	87.020	<.0001
Year 9	**<= 9000 sq-ft**	0.9488	65	<.0001		19549.046	1848.967	10.570	<.0001
					(Size)	12.449	0.364	34.160	<.0001
	> 9000 sq-ft	0.9906	85	<.0001		65806.833	10364.500	6.350	<.0001
					(Size)	9.889	0.105	93.930	<.0001
Year 10	**<= 9000 sq-ft**	0.9474	75	<.0001		20439.941	1613.178	12.670	<.0001
					(Size)	12.227	0.335	36.540	<.0001
	> 9000	0.9922	105	<.0001		59977.379	8649.269	6.930	<.0001

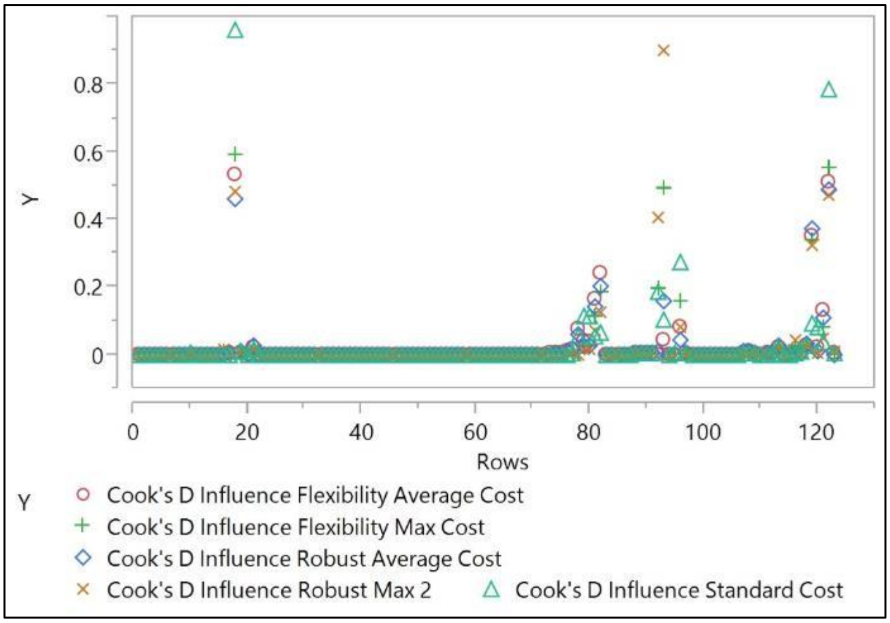
	sq-ft				(Size)	9.990	0.087	115.330	<.0001

Appendix H: LCC Distribution Fit Results

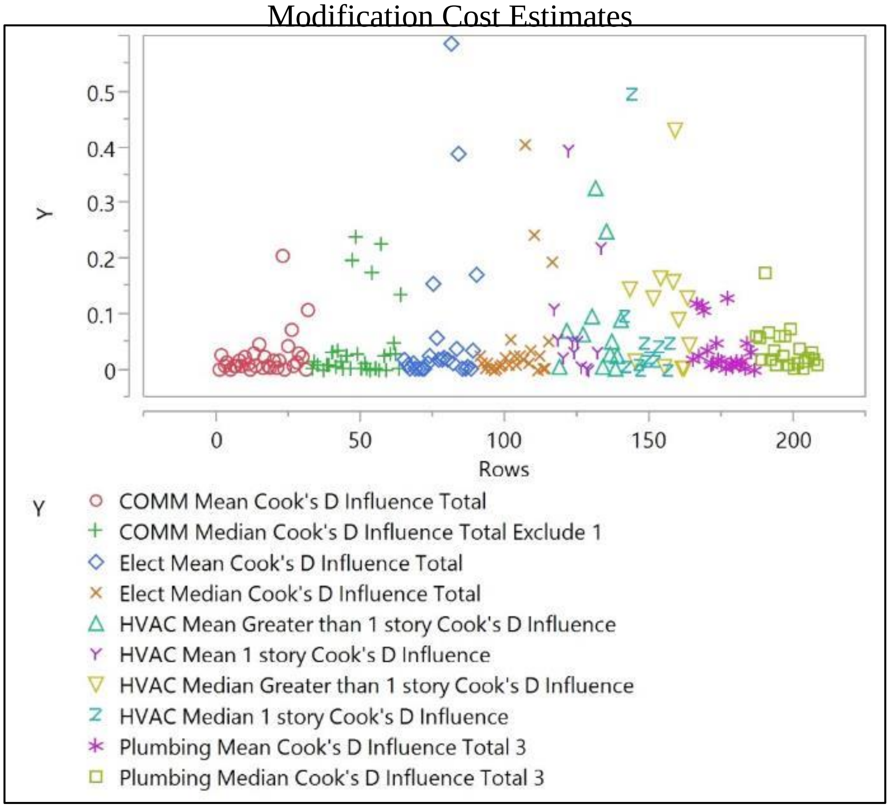
	Size	Adj R^2	N	Overall p-value	Parameter Estimates				
					Term	Estimate	Std Error	t Ratio	p-value
Year 11	<= 9000 sq-ft	0.9423	68	<.0001		20341.082	1791.449	11.350	<.0001
					(Size)	12.289	0.371	33.080	<.0001
	> 9000 sq-ft	0.9932	109	<.0001		63871.874	8452.167	7.560	<.0001
					(Size)	9.912	0.079	125.650	<.0001
Year 12	<= 9000 sq-ft	0.9321	75	<.0001		19274.219	2038.146	9.460	<.0001
					(Size)	12.891	0.404	31.900	<.0001
	> 9000 sq-ft	0.9934	120	<.0001		67661.237	7620.071	8.880	<.0001
					(Size)	9.895	0.074	133.780	<.0001
Year 13	<= 9000 sq-ft	0.9372	88	<.0001		17277.527	1956.685	8.830	<.0001
					(Size)	13.589	0.377	36.030	<.0001
	> 9000 sq-ft	0.9924	130	<.0001		66890.589	7888.957	8.480	<.0001
					(Size)	9.982	0.077	129.930	<.0001
Year 14	<= 9000 sq-ft	0.9452	85	<.0001		16765.308	1872.139	8.960	<.0001
					(Size)	13.884	0.365	38.090	<.0001
	> 9000 sq-ft	0.9930	115	<.0001		53423.187	6705.045	7.970	<.0001
					(Size)	10.374	0.082	127.030	<.0001
Year 15	<= 9000 sq-ft	0.9436	81	<.0001		17144.006	1952.931	8.780	<.0001
					(Size)	13.844	0.378	36.590	<.0001
	> 9000 sq-ft	0.9947	106	<.0001		45869.683	5840.415	7.850	<.0001
					(Size)	10.521	0.075	140.810	<.0001
Year 16	<= 9000 sq-ft	0.9400	88	<.0001		16337.326	1943.263	8.410	<.0001
					(Size)	14.136	0.383	36.930	<.0001
	> 9000 sq-ft	0.9949	111	<.0001		44598.959	5936.792	7.510	<.0001
					(Size)	10.601	0.073	145.790	<.0001
Year 17	<= 9000 sq-ft	0.9448	87	<.0001		16696.501	1942.788	8.590	<.0001
					(Size)	14.115	0.368	38.390	<.0001
	> 9000 sq-ft	0.9951	115	<.0001		46788.937	5597.626	8.360	<.0001
					(Size)	10.592	0.070	151.990	<.0001
Year 18	<= 9000 sq-ft	0.9468	86	<.0001		17586.624	1941.256	9.060	<.0001
					(Size)	13.999	0.360	38.920	<.0001
	> 9000 sq-ft	0.9952	113	<.0001		51920.552	4992.455	10.4	<.0001
					(Size)	10.488268	0.069076	151.84	<.0001

Appendix I: Cook's Distance Results

Initial Construction Cost Estimates

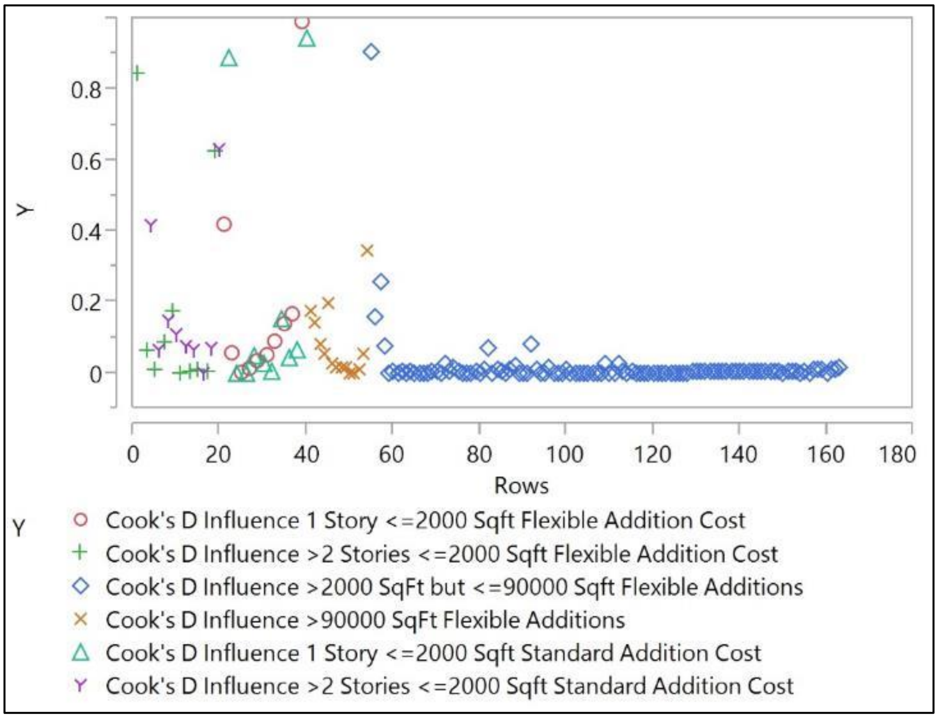


Modification Cost Estimates



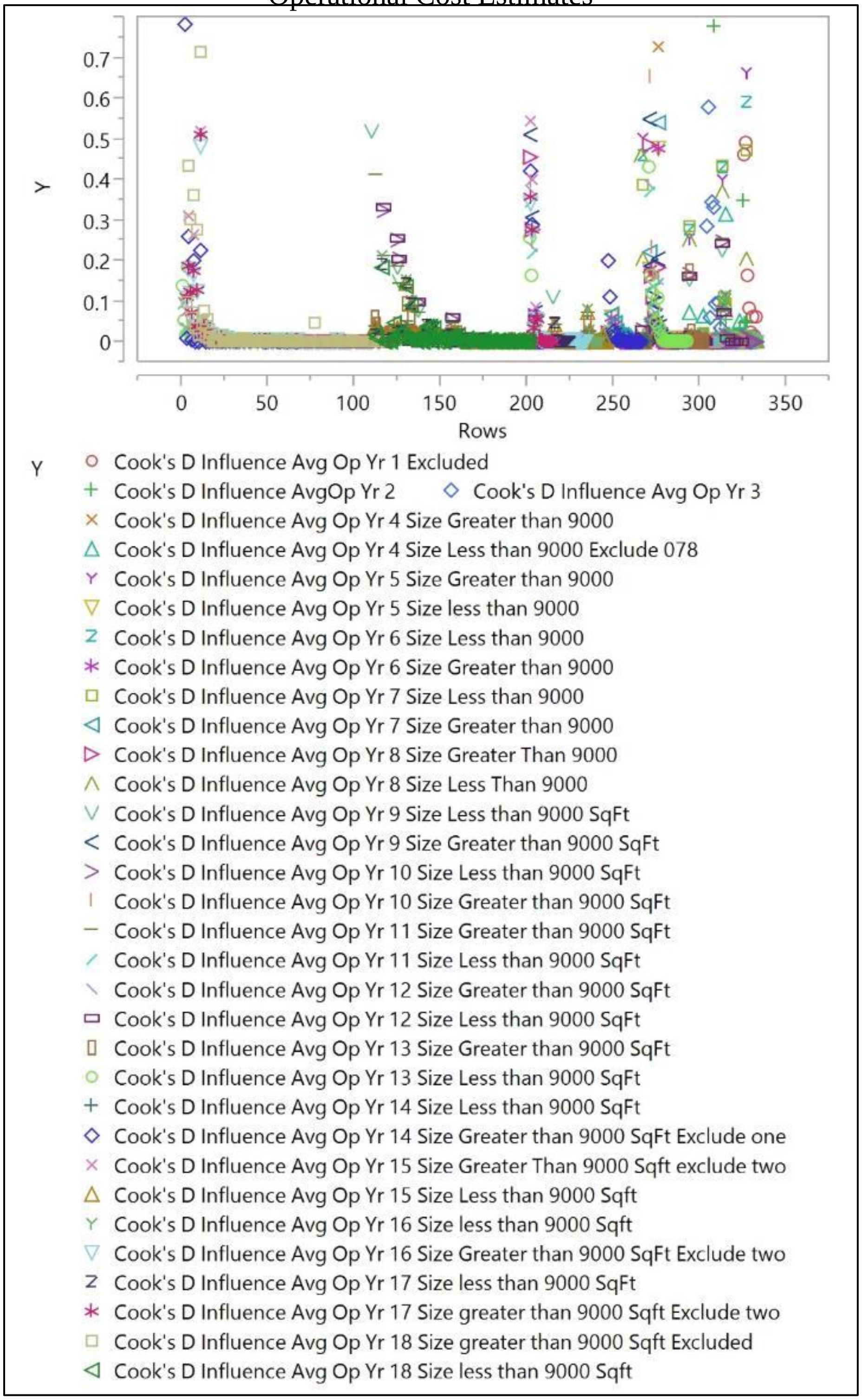
Appendix I: Cook's Distance Results

Addition Cost Estimates



Appendix I: Cook's Distance Results

Operational Cost Estimates



Appendix J: Cost Estimation Formulas

Initial Construction Cost Estimation Formulas		
Design	**Size**	**Cost Estimation Formulas**
Standard	All	=793066.85+204.497*(Facility Size)
Flexible	Average	=748729.11+267.127*(Facility Size)
	Large	=781230.04+302.581*(Facility Size)
Robust	Average	=800109.8+205.695*(Avg Facility Size)
	Large	=860659.69+202.424*(Large Facility Size)

Modification and Addition Cost Estimation Formulas		
System	**Size**	**Cost Estimation Formulas**
Standard	>1 Story & <=2000 sq-ft	=587770.49+255.3*(Size)+-0.034*(Size)^2
	>1 Story & <=2000 sq-ft	=762491.78+294.134*(Size)+-0.029*(Size)^2
Flexible	1 Story & <=2000 sq-ft	=110923.57+119.316*(Size)+-0.022*(Size)^2
	>1 Story & <=2000 sq-ft	=110923.57+119.316*(Size)+-0.022*(Size)^2
	>2000 sq-ft & <=90000 sq-ft	=242176.45+47.418*(Size)
	>90000 sq-ft	=1449143.5+32.733*(Size)
Comm	Median	=8540.873+3.117*(Size)
	Mean	=80771.311+7.227*(Size)
Electrical	Median	=76229.68+6.475*(Size)
	Mean	=72737.512+9.347*(Size)
HVAC	Median 1 Story	=154855.44+3.818*(Size)
	Median > 1 Story	=156490.77+3.948*(Size)
	Mean 1 Story	=171399.41+17.398*(Size)
	Mean > 1 Story	=196252.41+17.84*(Size)
Plumbing	Median	=86414.902+1.629*(Size)
	Mean	=80642.564+4.966*(Size)

Appendix J: Cost Estimation Formulas

Operational Costs Estimation Formulas		
Year	**Size**	**Cost Estimation Formulas**
1	**All**	=19236.529+12.214*(Size)
2	**All**	=27991.918+10.58*(Size)
3	**All**	=23453.037+11.464*(Size)
4	**<= 9000 sq-ft**	=26712.066+10.192*(Size)
	> 9000 sq-ft	=67787.387+9.611*(Size)
5	**<= 9000 sq-ft**	=22713.059+11.239*(Size)
	> 9000 sq-ft	=78682.76+9.61*(Size)
6	**<= 9000 sq-ft**	=22748.417+11.277*(Size)
	> 9000 sq-ft	=78682.76+9.61*(Size)
7	**<= 9000 sq-ft**	=22981.58+11.305*(Size)
	> 9000 sq-ft	=72239.718+9.639*(Size)
8	**<= 9000 sq-ft**	=22075.001+11.576*(Size)
	> 9000 sq-ft	=65505.38+9.887*(Size)
9	**<= 9000 sq-ft**	=19549.046+12.449*(Size)
	> 9000 sq-ft	=65806.833+9.889*(Size)
10	**<= 9000 sq-ft**	=20439.941+12.227*(Size)
	> 9000 sq-ft	=59977.379+9.99*(Size)
11	**<= 9000 sq-ft**	=20341.082+12.289*(Size)
	> 9000 sq-ft	=63871.874+9.912*(Size)
12	**<= 9000 sq-ft**	=19274.219+12.891*(Size)
	> 9000 sq-ft	=67661.237+9.895*(Size)
13	**<= 9000 sq-ft**	=17277.527+13.589*(Size)
	> 9000 sq-ft	=66890.589+9.982*(Size)
14	**<= 9000 sq-ft**	=16765.308+13.884*(Size)
	> 9000 sq-ft	=53423.187+10.374*(Size)
15	**<= 9000 sq-ft**	=17144.006+13.844*(Size)
	> 9000 sq-ft	=45869.683+10.521*(Size)
16	**<= 9000 sq-ft**	=16337.326+14.136*(Size)
	> 9000 sq-ft	=44598.959+10.601*(Size)
17	**<= 9000 sq-ft**	=16696.501+14.115*(Size)
	> 9000 sq-ft	=46788.937+10.592*(Size)
18	**<= 9000 sq-ft**	=17586.624+13.999*(Size)
	> 9000 sq-ft	=51920.552+10.488*(Size)

Appendix K: RStudio® Facility LCC Simulation Code

```
  ' Model Inputs'

## [1] " Model Inputs"

  Size = 20000
  NbrStories = 1
  CATCODE = 610284

  'Load libraries'

## [1] "Load libraries"

  library("triangle", lib.loc="~/R/win-library/3.2")

## Warning: package 'triangle' was built under R version 3.2.3

  ' Set Robust and Flexible size'

## [1] " Set Robust and Flexible size"

  RobustAvgSize = Size + Size*0.361050775471601
  RobustMaxSize = Size + Size*0.59958769138795

  ' Set logic statements based on model input that do not change when addition occurs'

## [1] " Set logic statements based on model input that do not change when addition occur
s"

  StoriesE1   = if(NbrStories==1)  {1} else {0}
  StoriesE2   = if(NbrStories==2)  {1} else {0}
  StoriesG2   = if(NbrStories>2)   {1} else {0}
  Code121     = if(CATCODE==610121){1} else {0}
  Code243     = if(CATCODE==610243){1} else {0}
  Code249     = if(CATCODE==610249){1} else {0}
  Code282     = if(CATCODE==610282){1} else {0}
  Code284     = if(CATCODE==610284){1} else {0}
  Code675     = if(CATCODE==610675){1} else {0}
  CodesBaseHQ = if(CATCODE==610281){1} else if(CATCODE==610287) {1} else{0}
  CodesLRS    = if(CATCODE==610121){1} else if(CATCODE==610142) {1} else if(CATCODE==6107
11) {1} else {0}

  ' Set logic statements based on model input that change when addition occurs'

## [1] " Set logic statements based on model input that change when addition occurs"

  '-Robust Avg Size less than 9K but greater than 4k'

## [1] "-Robust Avg Size less than 9K but greater than 4k"
```

```
  RASizeLE9K  = if(RobustAvgSize<=4000){0} else if(RobustAvgSize<=9000){1} else {0}
  '- Robust Max Size less than 9K but greater than 4k'
```

```
## [1] "- Robust Max Size less than 9K but greater than 4k"
```

```
  RMSizeLE9K  = if(RobustMaxSize<=4000){0} else if(RobustMaxSize<=9000){1} else {0}

  ' Determining demand probabilities that do not change when addition occurs'
```

```
## [1] " Determining demand probabilities that do not change when addition occurs"
```

```
  '- Any Size'
```

```
## [1] "- Any Size"
```

```
  ModP_Add_19   = exp(-2.1102132+2.1102132*StoriesG2+2.1102132*CodesBaseHQ)/(1+exp(-2.110
2132+2.1102132*StoriesG2+2.1102132*CodesBaseHQ))
  ModP_HVAC_7   = exp(-2.6692103+2.66921032*StoriesG2+1.97606314*Code284)/(1+exp(-2.66921
03+2.66921032*StoriesG2+1.97606314*Code284))
  ModP_COMM_4   = exp(-4.3944492+3.35299528*StoriesE2+4.39444915*StoriesG2+3.14168618*Cod
e284+3.70130197*CodesLRS)/(1+exp(-4.3944492+3.35299528*StoriesE2+4.39444915*StoriesG2+3.1
4168618*Code284+3.70130197*CodesLRS))+0.01
  ModP_COMM_8   = exp(-3.3900241+2.3485702*StoriesE2+4.08317126*StoriesG2+3.39002408*Code
121)/(1+exp(-3.3900241+2.3485702*StoriesE2+4.08317126*StoriesG2+3.39002408*Code121))
  ModP_Elect_6  = exp(-4.3944492+2.83630453*StoriesE2+6.00388707*StoriesG2+3.14168618*Cod
e284+3.70130197*CodesLRS)/(1+exp(-4.3944492+2.83630453*StoriesE2+6.00388707*StoriesG2+3.1
4168618*Code284+3.70130197*CodesLRS))
  ModP_Elect_19 = exp(-2.5649493+3.25809653*StoriesG2+1.55334843*Code243+2.56494935*Code6
75)/(1+exp(-2.5649493+3.25809653*StoriesG2+1.55334843*Code243+2.56494935*Code675))
  ModP_Plumb_7  = exp(-2.8286926+3.30630474*StoriesG2+1.88689868*Code249)/(1+exp(-2.82869
26+3.30630474*StoriesG2+1.88689868*Code249))
  ModP_Plumb_19 = exp(-2.3702437+2.37024374*StoriesG2)/(1+exp(-2.3702437+2.37024374*Stori
esG2))
  '- RobustAvgSize'
```

```
## [1] "- RobustAvgSize"
```

```
  RAModP_HVAC_19   = exp(-1.4422318-2.5173629*StoriesE1+1.82316545*RASizeLE9K+3.95959468*C
ode121+1.93840929*ModP_HVAC_7)/(1+exp(-1.4422318-2.5173629*StoriesE1+1.82316545*RASizeLE9
K+3.95959468*Code121+1.93840929*ModP_HVAC_7))
  RAModP_COMM_19   = exp(-4.3576764+4.19570126*StoriesG2+2.31190654*RASizeLE9K+3.86710115*
Code675+2.21037167*ModP_COMM_8)/(1+exp(-4.3576764+4.19570126*StoriesG2+2.31190654*RASizeL
E9K+3.86710115*Code675+2.21037167*ModP_COMM_8))
  '- RobustMaxSize'
```

```
## [1] "- RobustMaxSize"
```

```
  RMModP_HVAC_19   = exp(-1.4422318-2.5173629*StoriesE1+1.82316545*RMSizeLE9K+3.95959468*C
ode121+1.93840929*ModP_HVAC_7)/(1+exp(-1.4422318-2.5173629*StoriesE1+1.82316545*RMSizeLE9
K+3.95959468*Code121+1.93840929*ModP_HVAC_7))
```

```
  RMModP_COMM_19  = exp(-4.3576764+4.19570126*StoriesG2+2.31190654*RMSizeLE9K+3.86710115*
Code675+2.21037167*ModP_COMM_8)/(1+exp(-4.3576764+4.19570126*StoriesG2+2.31190654*RMSizeL
E9K+3.86710115*Code675+2.21037167*ModP_COMM_8))


  'Declare Variables used in the simulation'

## [1] "Declare Variables used in the simulation"

  #Variables used in this lifecycle
  OpCost           = c(0,1:18)
  AvgOpCost        = c(0,1:18)
  MaxOpCost        = c(0,1:18)

  HVACCostMean     = c(0,1:18)
  HVACCostMedian   = c(0,1:18)
  COMMCostMean     = c(0,1:18)
  COMMCostMedian   = c(0,1:18)
  ElectCostMean    = c(0,1:18)
  ElectCostMedian  = c(0,1:18)
  PlumbCostMean    = c(0,1:18)
  PlumbCostMedian  = c(0,1:18)
  AddCost          = c(0,1:18)
  FlexAvgAddCost   = c(0,1:18)
  RobustAvgAddCost = c(0,1:18)
  FlexMaxAddCost   = c(0,1:18)
  RobustMaxAddCost = c(0,1:18)

  #Variables used throughout the Simulation

  StdCashFlow      = c(1:19*n)
  FlexAvgCashFlow  = c(1:19*n)
  FlexMaxCashFlow  = c(1:19*n)
  RobAvgCashFlow   = c(1:19*n)
  RobMaxCashFlow   = c(1:19*n)

  LCStdTotCostMean   = c(1:n)
  LCStdTotCostMedian = c(1:n)
  LCFlexAvgTotCost   = c(1:n)
  LCFlexMaxTotCost   = c(1:n)
  LCRobAvgTotCost    = c(1:n)
  LCRobMaxTotCost    = c(1:n)

  ' SIMULATION'

## [1] " SIMULATION"
```

```
  for(i in 1:n)
  {
    ' Creates new size variables that can be changed for each potential lifecycle'
    TSize  = Size
    TASize = RobustAvgSize
    TMSize = RobustMaxSize

    ' Set logic statements based on model input that change when addition occurs'
    '- Standard Size less than 9K but greater than 4k'
    SizeLE9K    = if(TSize<=4000)    {0} else if (TSize<=9000) {1} else {0}

    ' Determining demand probabilities that change when addition occurs'
    '- Standard Size'
    ModP_HVAC_19  = exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9K+3.95959468*Cod
e121+1.93840929*ModP_HVAC_7)/(1+exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9K+3.
95959468*Code121+1.93840929*ModP_HVAC_7))
    ModP_COMM_19  = exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeLE9K+3.86710115*Co
de675+2.21037167*ModP_COMM_8)/(1+exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeLE9K+
3.86710115*Code675+2.21037167*ModP_COMM_8))

    'Triangular Distrobution to represent the undercertainty of the cost estimates'
    '- Initial Costs'
    TriDisIntStd = rtriangle(1, 0.809360, 1.212252,0.975466)
    TriDisIntRoAv = rtriangle(1, 0.8202, 1.1791,    0.9779)
    TriDisIntRoMx = rtriangle(1, 0.7757, 1.1769, 0.9714)
    TriDisIntFlAv = rtriangle(1, 0.8527, 1.1822,  0.9819)
    TriDisIntFlMx = rtriangle(1, 0.7459, 1.1816,    0.9420)
    '- Modification Costs'
    TriDisModCOMMMedian = rtriangle(18, 0.9503, 1.0687, 1.0072)
    TriDisModCOMMMean = rtriangle(18, 0.7896, 1.1275, 1.0104)
    TriDisModElectricMedian = rtriangle(18, 0.7933, 1.2734, 1.0047)
    TriDisModElectricMean = rtriangle(18, 0.7896, 1.1275, 1.0210)
    TriDisModHVACMedian = rtriangle(18, 0.9474, 1.1216, 1.0105)
    TriDisModHVACMean = rtriangle(18, 0.9448, 1.0755, 1.0067)
    TriDisModPlumbMedian = rtriangle(18, 0.9052, 1.0829, 1.0059)
    TriDisModPlumbMean = rtriangle(18, 0.9285, 1.0652, 1.0004)
    '-Addition Costs'
    TriDisModStdAddStd = rtriangle(18, 0.8991, 1.2315, 1.0350)
    TriDisModStdAddFlex = rtriangle(18, 0.8928, 1.2009, 1.0370)

    '-Operational Costs'
    TriDisOpYr01 = rtriangle(1,0.9451, 1.0385, 1.0043)
    TriDisOpYr02 = rtriangle(1,0.8889, 1.1070, 0.9869)
    TriDisOpYr03 = rtriangle(1,0.9128, 1.1085, 0.9909)
    TriDisOpYr04 = rtriangle(1,0.7222, 1.1377, 0.9816)
    TriDisOpYr05 = rtriangle(1,0.6417, 1.1317, 0.9724)
    TriDisOpYr06 = rtriangle(1,0.6417, 1.1317, 0.9732)
```

```
    TriDisOpYr07 = rtriangle(1,0.6870, 1.1325, 0.9783)
    TriDisOpYr08 = rtriangle(1,0.7167, 1.1208, 0.9790)
    TriDisOpYr09 = rtriangle(1,0.7144, 1.1692, 0.9799)
    TriDisOpYr10 = rtriangle(1,0.7493, 1.1704, 0.9859)
    TriDisOpYr11 = rtriangle(1,0.7268, 1.1684, 0.9853)
    TriDisOpYr12 = rtriangle(1,0.7002, 1.1630, 0.9848)
    TriDisOpYr13 = rtriangle(1,0.6989, 1.1522, 0.9844)
    TriDisOpYr14 = rtriangle(1,0.8485, 1.1439, 0.9947)
    TriDisOpYr15 = rtriangle(1,0.8683, 1.1415, 1.0010)
    TriDisOpYr16 = rtriangle(1,0.8545, 1.1776, 1.0014)
    TriDisOpYr17 = rtriangle(1,0.7947, 1.1761, 0.9994)
    TriDisOpYr18 = rtriangle(1,0.4860, 1.1758, 0.9964)

    '- Initial Cost'
    '-- Standard Design'
    IntStdCost = (793066.85 + 204.49704*TSize)*TriDisIntStd
    '-- Robust Design'
    '---Robust Average'
    IntRobustAvgCost = (800112.78 + 205.69462*TASize)*TriDisIntRoAv
    '---Robust Maxium'
    IntRobustMaxCost = (860659.69 + 202.42382*TMSize)*TriDisIntRoMx
    '-- Flexible Design'
    '---Flexible Average'
    IntFlexAvgCost = (748729.11 + 267.12747*TSize)*TriDisIntFlAv
    '---Flexible Maxium'
    IntFlexMaxCost = (781230.04 + 302.58149*TSize)*TriDisIntFlMx

    '- Year 1 Predicted Costs'
    '---Annual operational costs for each facility Size'
    OpCost [2]     = (19236.529 + 12.213995*TSize)*TriDisOpYr01
    AvgOpCost [2]  = (19236.529 + 12.213995*TASize)*TriDisOpYr01
    MaxOpCost [2]  = (19236.529 + 12.213995*TMSize)*TriDisOpYr01

    '---Modifications predicted in Lifecycle and their costs'
    '----HVAC Modification'
    'Random variable used to determine what year modification occured'
    HVAC7yrRandP = runif(1, min = 0, max = 1) # P = Period modification occured
    HVAC7yrRandY = runif(1, min = 0, max = 1) # Y = Year modification occured
    'If statement determines if modification occurred it the set time period'
    if(HVAC7yrRandP<ModP_HVAC_7)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if(HVAC7yrRandY<=0.0769)
      {
        if(NbrStories == 1)
        {
```

```
          HVACCostMean [2] = (171399.41 + 17.39759*TSize)*TriDisModHVACMean[1]
          HVACCostMedian [2] = (154855.44 + 3.81795606*TSize)*TriDisModHVACMedian[1]
        }
        else
        {
          HVACCostMean [2] = 196252.41 + 17.839797*TSize
          HVACCostMedian [2] = 156490.77 + 3.9482492*TSize
        }

      } else
      {
        HVACCostMean [2] = 0
        HVACCostMedian [2] = 0
      }

    } else
    {
      HVACCostMean [2] = 0
      HVACCostMedian [2] = 0
    }
    '----COMM Modification'
    'Random variable used to determine what year modification occured'
    COMM4yrRandP = runif(1, min = 0, max = 1) # P = Period of modification
    COMM4yrRandY = runif(1, min = 0, max = 1) # Y = Year of modification
    'If statement determines if modification occurred it the set time period'
    if(COMM4yrRandP<ModP_COMM_4)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if(COMM4yrRandY<=0.1724)
      {
        COMMCostMean [2] = (80771.311 + 7.2269841*TSize)*TriDisModCOMMMean[1]
        COMMCostMedian [2] = (85440.873 + 3.1165737*TSize)*TriDisModCOMMMedian[1]

      } else
      {
        COMMCostMean [2] = 0
        COMMCostMedian [2] = 0
      }
    }else
    {
      COMMCostMean [2] = 0
      COMMCostMedian [2] = 0
    }
    '----Electrical Modification'
    'Random variable used to determine what year modification occured'
    Elect6yrRandP = runif(1, min = 0, max = 1)
```

```
    Elect6yrRandY = runif(1, min = 0, max = 1)
    'If statement determines if modification occurred it the set time period'
    if(Elect6yrRandP<ModP_Elect_6)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if(Elect6yrRandY<=0.1667)
      {
        ElectCostMean [2] = (72737.512 + 9.3469036*TSize)*TriDisModElectricMean[1]
        ElectCostMedian [2] = (76229.68 + 6.4750386*TSize)*TriDisModElectricMedian[1]
      } else
      {
        ElectCostMean [2] = 0
        ElectCostMedian [2] = 0
      }
    }else
    {
      ElectCostMean [2] = 0
      ElectCostMedian [2] = 0
    }
    '----Plumbing Modification'
    'Random variable used to determine what year modification occured'
    Plumb7yrRandP = runif(1, min = 0, max = 1) # P = Period of Modification
    Plumb7yrRandY = runif(1, min = 0, max = 1) # Y = Year of Modification

    'If statement determines if modification occurred it the set time period'
    if(Plumb7yrRandP<ModP_Plumb_7)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if(Plumb7yrRandY<=0.0333)
      {
        PlumbCostMean [2] = (80642.564 + 4.9662331*TSize)*TriDisModPlumbMean[1]
        PlumbCostMedian [2] = (86414.902 + 1.6289302*TSize)*TriDisModPlumbMedian[1]
      } else
      {
        PlumbCostMean [2] = 0
        PlumbCostMedian [2] = 0
      }
    } else
    {
      PlumbCostMean [2] = 0
      PlumbCostMedian [2] = 0
    }
    '----Facility Addition'
    'Random variable used to determine what year modification occured'
    Add19yrRandP = runif(1, min = 0, max = 1) # Period Rand Number
```

```
    Add19yrRandY = runif(1, min = 0, max = 1) # Year Rand Number
    'If statement determines if modification occurred it the set time period'
    if(Add19yrRandP<ModP_Add_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if(Add19yrRandY<=0.0741)
      {
        'Random selection of addition size based on weibull distro'
        AddSize = rweibull(1, shape = 1.3062133, scale = 1742.5275)
        'Standard Addition Cost'
        'updates the facility size for a potential facility lifecycle'
        TSize = TSize + AddSize
        ' Set logic statements to the new facility size'
        '-Standard Size less than 9K but greater than 4k'
        SizeLE9K    = if(TSize<=4000)    {0} else if (TSize<=9000) {1} else {0}
        ' Updates modification that change when addition occurs'
        '-Standard Size'
        ModP_HVAC_19  = exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9K+3.95959468
*Code121+1.93840929*ModP_HVAC_7)/(1+exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9
K+3.95959468*Code121+1.93840929*ModP_HVAC_7))
        ModP_COMM_19  = exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeLE9K+3.8671011
5*Code675+2.21037167*ModP_COMM_8)/(1+exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeL
E9K+3.86710115*Code675+2.21037167*ModP_COMM_8))
        'Recodes the cost of the addition based on size and number of stories'
        if(AddSize <= 2000)
        {
          if(NbrStories == 1)
          {
            AddCost [2] = (587770.49 + 255.30046*AddSize - 0.0342524*(AddSize-1100)^2)*Tr
iDisModStdAddStd[1]
            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {  #if the addition exceed orginal design estiamte of robust and flex avg
              FlexAvgAddCost [2]   = (587770.49 + 255.30046*(TSize-TASize) - 0.0342524*((
TSize-TASize)-1100)^2 )*TriDisModStdAddStd[1]
              FlexAvgAddCost [2]   = FlexAvgAddCost [2] + (102596.39 + 96.037325*(AddSize
-TSize+TASize) - 0.0293642*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[1]
              RobustAvgAddCost [2] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSiz
e-1100)^2)*TriDisModStdAddStd[1]
            }else
            {
              FlexAvgAddCost [2]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize)
-1100)^2)*TriDisModStdAddFlex[1]
              RobustAvgAddCost [2] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
```

```
            if(TSize>TMSize)
            {
              FlexMaxAddCost [2]   = (587770.49 + 255.30046*(TSize-TMSize) - 0.0342524*((
TSize-TMSize)-1100)^2)*TriDisModStdAddStd[1]
              FlexMaxAddCost [2]   = FlexMaxAddCost [2] + (102596.39 + 96.037325*(AddSize
-TSize+TMSize) - 0.0293642*((AddSize-TSize+TMSize)-1100)^2)*TriDisModStdAddFlex[1]
              RobustMaxAddCost [2] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSiz
e-1100)^2)*TriDisModStdAddStd[1]
            }else
            {
              FlexMaxAddCost [2]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize)
-1100)^2)*TriDisModStdAddFlex[1]
              RobustMaxAddCost [2] = 0
            }
          } else
          {
            AddCost [2] = (762491.78 + 294.13388*AddSize - 0.0289768*(AddSize-1100)^2)*Tr
iDisModStdAddStd[1]

            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {
              FlexAvgAddCost [2]   = (762491.78 + 294.13388*(TSize-TASize) - 0.0289768*((
TSize-TASize)-1100)^2)*TriDisModStdAddStd[1]
              FlexAvgAddCost [2]   = FlexAvgAddCost [2] + (120923.57 + 119.31587*(AddSize
-TSize+TASize) - 0.022339*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[1]
              RobustAvgAddCost [2] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSiz
e-1100)^2)*TriDisModStdAddStd[1]
            }else
            {
              FlexAvgAddCost [2]   = (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSiz
e)-1100)^2)*TriDisModStdAddFlex[1]
              RobustAvgAddCost [2] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
            if(TSize>TMSize)
            {
              FlexMaxAddCost [2]   = (762491.78 + 294.13388*(TSize-TMSize) - 0.0289768*((
TSize-TMSize)-1100)^2 )*TriDisModStdAddStd[1]
              FlexMaxAddCost [2]   = FlexMaxAddCost [2] + (120923.57 + 119.31587*(AddSize
-TSize+TMSize) - 0.022339*((AddSize-TSize+TMSize)-1100)^2 )*TriDisModStdAddFlex[1]
              RobustMaxAddCost [2] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSiz
e-1100)^2)*TriDisModStdAddStd[1]
            }else
            {
              FlexMaxAddCost [2]= (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSize)-
1100)^2)*TriDisModStdAddFlex[1]
```

```
              RobustMaxAddCost [2] = 0
            }
          }
        } else
        {
          AddCost [2] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[1]

          'Determines addition Cost for average flexible and robust designs'
          if(TSize>TASize)
          {
            FlexAvgAddCost [2]   = (841127.96 + 208.01641*(TSize-TASize) - 0.0001798*((TS
ize-TASize)-27413.8)^2 + 0.0000000010082*((TSize-TASize)-27413.8)^3)*TriDisModStdAddStd[1
]
            FlexAvgAddCost [2]   = FlexAvgAddCost [2] + (748729.11 + 267.12747*(AddSize-T
Size+TASize))*TriDisModStdAddFlex[1]
            RobustAvgAddCost [2]  = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[1]
          }else
          {
            FlexAvgAddCost [2]   = (748729.11 + 267.12747*AddSize)*TriDisModStdAddFlex[1]
            RobustAvgAddCost [2] = 0
          }
          'Determines addition Cost for max flexible and robust designs'
          if(TSize>TMSize)
          {
            FlexMaxAddCost [2]   = (841127.96 + 208.01641*(TSize-TMSize) - 0.0001798*((TS
ize-TMSize)-27413.8)^2 + 0.0000000010082*((TSize-TMSize)-27413.8)^3)*TriDisModStdAddStd[1
]
            FlexMaxAddCost [2]   = FlexMaxAddCost [2] + (727335.73 + 308.56524*(AddSize-T
Size+TMSize) - 0.000058747*((AddSize-TSize+TMSize)-27413.8)^2)*TriDisModStdAddFlex[1]
            RobustMaxAddCost [2] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[1]
          }else
          {
            FlexMaxAddCost [2]   = (727335.73 + 308.56524*(AddSize) - 0.000058747*((AddSi
ze)-27413.8)^2)*TriDisModStdAddFlex[1]
            RobustMaxAddCost [2] = 0
          }
        }
      } else
      {
        AddCost [2] = 0
        FlexAvgAddCost [2] = 0
        FlexMaxAddCost [2] = 0
        RobustAvgAddCost [2] = 0
        RobustMaxAddCost [2] = 0
      }
    } else
    {
```

```
      AddCost [2] = 0
      FlexAvgAddCost [2] = 0
      FlexMaxAddCost [2] = 0
      RobustAvgAddCost [2] = 0
      RobustMaxAddCost [2] = 0
    }

    '- Year 2 Predicted Costs'
    '---Annual operational costs for each facility Size'
    OpCost [3]     = (27991.918 + 10.580487*TSize)*TriDisOpYr02
    AvgOpCost [3]  = (27991.918 + 10.580487*TASize)*TriDisOpYr02
    MaxOpCost [3]  = (27991.918 + 10.580487*TMSize)*TriDisOpYr02
    '---Modifications predicted in Lifecycle and their costs'
    '----HVAC Modification'
    'If statement determines if modification occurred it the set time period'
    if(HVAC7yrRandP<ModP_HVAC_7)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if( (HVAC7yrRandY<=0.1923) & (HVAC7yrRandY>0.0769))
      {
        if(NbrStories == 1)
        {
          HVACCostMean [3] = (171399.41 + 17.39759*TSize)*TriDisModHVACMean[2]
          HVACCostMedian [3] = (154855.44 + 3.81795606*TSize)*TriDisModHVACMedian[2]
        }
        else
        {
          HVACCostMean [3] = 196252.41 + 17.839797*TSize
          HVACCostMedian [3] = 156490.77 + 3.9482492*TSize
        }

      } else
      {
        HVACCostMean [3] = 0
        HVACCostMedian [3] = 0
      }
    } else
    {
      HVACCostMean [3] = 0
      HVACCostMedian [3] = 0
    }
    '----COMM Modification'
    'If statement determines if modification occurred it the set time period'
    if(COMM4yrRandP<ModP_COMM_4)
    {
      'If Statement determines if the modification occured in this year and records the c
```

```
ost'
      if((COMM4yrRandY<=0.4828) & (COMM4yrRandY>0.1724))
      {
        COMMCostMean [3] = (80771.311 + 7.2269841*TSize)*TriDisModCOMMMean[2]
        COMMCostMedian [3] = (85440.873 + 3.1165737*TSize)*TriDisModCOMMMedian[2]

      } else
      {
        COMMCostMean [3] = 0
        COMMCostMedian [3] = 0
      }
    }else
    {
      COMMCostMean [3] = 0
      COMMCostMedian [3] = 0
    }
    '----Electrical Modification'
    'If statement determines if modification occurred it the set time period'
    if(Elect6yrRandP<ModP_Elect_6)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Elect6yrRandY<=0.4286) & (Elect6yrRandY>0.1667))
      {
        ElectCostMean [3] = (72737.512 + 9.3469036*TSize)*TriDisModElectricMean[2]
        ElectCostMedian [3] = (76229.68 + 6.4750386*TSize)*TriDisModElectricMedian[2]
      } else
      {
        ElectCostMean [3] = 0
        ElectCostMedian [3] = 0
      }
    }else
    {
      ElectCostMean [3] = 0
      ElectCostMedian [3] = 0
    }
    '----Plumbing Modification'
    'If statement determines if modification occurred it the set time period'
    if(Plumb7yrRandP<ModP_Plumb_7)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Plumb7yrRandY<=0.2333) & (Plumb7yrRandY>0.0333))
      {
        PlumbCostMean [3] = (80642.564 + 4.9662331*TSize)*TriDisModPlumbMean[2]
        PlumbCostMedian [3] = (86414.902 + 1.6289302*TSize)*TriDisModPlumbMedian[2]
      } else
```

```
      {
        PlumbCostMean [3] = 0
        PlumbCostMedian [3] = 0
      }
    } else
    {
      PlumbCostMean [3] = 0
      PlumbCostMedian [3] = 0
    }
    '----Facility Addition'
    'If statement determines if modification occurred it the set time period'
    if(Add19yrRandP<ModP_Add_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Add19yrRandY<=0.1852) & (Add19yrRandY>0.0741))
      {
        'Random selection of addition size based on weibull distro'
        AddSize = rweibull(1, shape = 1.3062133, scale = 1742.5275)
        'Updates the facility size for a potential facility lifecycle'
        TSize = TSize + AddSize
        'Set logic statements to the new facility size'
        '-Standard Size less than 9K but greater than 4k'
        SizeLE9K    = if(TSize<=4000)    {0} else if (TSize<=9000) {1} else {0}
        'Updates modification that change when addition occurs'
        '-Standard Size'
        ModP_HVAC_19  = exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9K+3.95959468
*Code121+1.93840929*ModP_HVAC_7)/(1+exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9
K+3.95959468*Code121+1.93840929*ModP_HVAC_7))
        ModP_COMM_19  = exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeLE9K+3.8671011
5*Code675+2.21037167*ModP_COMM_8)/(1+exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeL
E9K+3.86710115*Code675+2.21037167*ModP_COMM_8))
        'Recodes the cost of the addition based on size and number of stories'
        if(AddSize <= 2000)
        {
          if(NbrStories == 1)
          {
            AddCost [3] = (587770.49 + 255.30046*AddSize - 0.0342524*(AddSize-1100)^2)*Tr
iDisModStdAddStd[2]

            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {
              FlexAvgAddCost [3]   = (587770.49 + 255.30046*(TSize-TASize) - 0.0342524*((
TSize-TASize)-1100)^2 )*TriDisModStdAddStd[2]
              FlexAvgAddCost [3]   = FlexAvgAddCost [3] + (102596.39 + 96.037325*(AddSize
-TSize+TASize) - 0.0293642*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[2]
```

```
              RobustAvgAddCost [3] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSiz
e-1100)^2)*TriDisModStdAddStd[2]
            }else
            {
              FlexAvgAddCost [3]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize)
-1100)^2)*TriDisModStdAddFlex[2]
              RobustAvgAddCost [3] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
            if(TSize>TMSize)
            {
              FlexMaxAddCost [3]   = (587770.49 + 255.30046*(TSize-TMSize) - 0.0342524*((
TSize-TMSize)-1100)^2)*TriDisModStdAddStd[2]
              FlexMaxAddCost [3]   = FlexMaxAddCost [3] + (102596.39 + 96.037325*(AddSize
-TSize+TMSize) - 0.0293642*((AddSize-TSize+TMSize)-1100)^2)*TriDisModStdAddFlex[2]
              RobustMaxAddCost [3] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSiz
e-1100)^2)*TriDisModStdAddStd[2]
            }else
            {
              FlexMaxAddCost [3]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize)
-1100)^2)*TriDisModStdAddFlex[2]
              RobustMaxAddCost [3] = 0
            }
          } else
          {
            AddCost [3] = (762491.78 + 294.13388*AddSize - 0.0289768*(AddSize-1100)^2)*Tr
iDisModStdAddStd[2]

            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {
              FlexAvgAddCost [3]   = (762491.78 + 294.13388*(TSize-TASize) - 0.0289768*((
TSize-TASize)-1100)^2)*TriDisModStdAddStd[2]
              FlexAvgAddCost [3]   = FlexAvgAddCost [3] + (120923.57 + 119.31587*(AddSize
-TSize+TASize) - 0.022339*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[2]
              RobustAvgAddCost [3] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSiz
e-1100)^2)*TriDisModStdAddStd[2]
            }else
            {
              FlexAvgAddCost [3]   = (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSiz
e)-1100)^2)*TriDisModStdAddFlex[2]
              RobustAvgAddCost [3] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
            if(TSize>TMSize)
            {
              FlexMaxAddCost [3]   = (762491.78 + 294.13388*(TSize-TMSize) - 0.0289768*((
```

```
TSize-TMSize)-1100)^2 )*TriDisModStdAddStd[2]
              FlexMaxAddCost [3]   = FlexMaxAddCost [3] + (120923.57 + 119.31587*(AddSize
-TSize+TMSize) - 0.022339*((AddSize-TSize+TMSize)-1100)^2 )*TriDisModStdAddFlex[2]
              RobustMaxAddCost [3] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSiz
e-1100)^2)*TriDisModStdAddStd[2]
            }else
            {
              FlexMaxAddCost [3]= (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSize)-
1100)^2)*TriDisModStdAddFlex[2]
              RobustMaxAddCost [3] = 0
            }
          }
        } else
        {
          AddCost [3] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[2]

          'Determines addition Cost for average flexible and robust designs'
          if(TSize>TASize)
          {
            FlexAvgAddCost [3]   = (841127.96 + 208.01641*(TSize-TASize) - 0.0001798*((TS
ize-TASize)-27413.8)^2 + 0.0000000010082*((TSize-TASize)-27413.8)^3)*TriDisModStdAddStd[2
]
            FlexAvgAddCost [3]   = FlexAvgAddCost [3] + (748729.11 + 267.12747*(AddSize-T
Size+TASize))*TriDisModStdAddFlex[2]
            RobustAvgAddCost [3] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[2]
          }else
          {
            FlexAvgAddCost [3]   = (748729.11 + 267.12747*AddSize)*TriDisModStdAddFlex[2]
            RobustAvgAddCost [3] = 0
          }
          'Determines addition Cost for max flexible and robust designs'
          if(TSize>TMSize)
          {
            FlexMaxAddCost [3]   = (841127.96 + 208.01641*(TSize-TMSize) - 0.0001798*((TS
ize-TMSize)-27413.8)^2 + 0.0000000010082*((TSize-TMSize)-27413.8)^3)*TriDisModStdAddStd[2
]
            FlexMaxAddCost [3]   = FlexMaxAddCost [3] + (727335.73 + 308.56524*(AddSize-T
Size+TMSize) - 0.000058747*((AddSize-TSize+TMSize)-27413.8)^2)*TriDisModStdAddFlex[2]
            RobustMaxAddCost [3] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[2]
          }else
          {
            FlexMaxAddCost [3]   = (727335.73 + 308.56524*(AddSize) - 0.000058747*((AddSi
ze)-27413.8)^2)*TriDisModStdAddFlex[2]
            RobustMaxAddCost [3] = 0
          }
        }
      } else
```

```
      {
        AddCost [3] = 0
        FlexAvgAddCost [3] = 0
        FlexMaxAddCost [3] = 0
        RobustAvgAddCost [3] = 0
        RobustMaxAddCost [3] = 0
      }
    } else
    {
      AddCost [3] = 0
      FlexAvgAddCost [3] = 0
      FlexMaxAddCost [3] = 0
      RobustAvgAddCost [3] = 0
      RobustMaxAddCost [3] = 0
    }

    '- Year 3 Predicted Costs'
    '---Annual operational costs for each facility Size'
    OpCost [4]     = (23453.037 + 11.463986*TSize)*TriDisOpYr03
    AvgOpCost [4]  = (23453.037 + 11.463986*TASize)*TriDisOpYr03
    MaxOpCost [4]  = (23453.037 + 11.463986*TMSize)*TriDisOpYr03

    '---Modifications predicted in Lifecycle and their costs'
    '----HVAC Modification'
    'If statement determines if modification occurred it the set time period'
    if(HVAC7yrRandP<ModP_HVAC_7)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((HVAC7yrRandY<=0.3846) & (HVAC7yrRandY>0.2692))
      {
        if(NbrStories == 1)
        {
          HVACCostMean [4] = (171399.41 + 17.39759*TSize)*TriDisModHVACMean[3]
          HVACCostMedian [4] = (154855.44 + 3.81795606*TSize)*TriDisModHVACMedian[3]
        }
        else
        {
          HVACCostMean [4] = (196252.41 + 17.839797*TSize)*TriDisModHVACMean[3]
          HVACCostMedian [4] = (156490.77 + 3.9482492*TSize)*TriDisModHVACMedian[3]
        }

      } else
      {
        HVACCostMean [4] = 0
        HVACCostMedian [4] = 0
      }
```

```
    } else
    {
      HVACCostMean [4] = 0
      HVACCostMedian [4] = 0
    }
    '----COMM Modification'
    'If statement determines if modification occurred it the set time period'
    if(COMM4yrRandP<ModP_COMM_4)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((COMM4yrRandY<=0.7241) & (COMM4yrRandY>0.4828))
      {
        COMMCostMean [4] = (80771.311 + 7.2269841*TSize)*TriDisModCOMMMean[3]
        COMMCostMedian [4] = (85440.873 + 3.1165737*TSize)*TriDisModCOMMMedian[3]

      } else
      {
        COMMCostMean [4] = 0
        COMMCostMedian [4] = 0
      }
    }else
    {
      COMMCostMean [4] = 0
      COMMCostMedian [4] = 0
    }
    '----Electrical Modification'
    'If statement determines if modification occurred it the set time period'
    if(Elect6yrRandP<ModP_Elect_6)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Elect6yrRandY<=0.7143) & (Elect6yrRandY>0.4286))
      {
        ElectCostMean [4] = (72737.512 + 9.3469036*TSize)*TriDisModElectricMean[3]
        ElectCostMedian [4] = (76229.68 + 6.4750386*TSize)*TriDisModElectricMedian[3]
      } else
      {
        ElectCostMean [4] = 0
        ElectCostMedian [4] = 0
      }
    }else
    {
      ElectCostMean [4] = 0
      ElectCostMedian [4] = 0
    }
    '----Plumbing Modification'
```

```
    'If statement determines if modification occurred it the set time period'
    if(Plumb7yrRandP<ModP_Plumb_7)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Plumb7yrRandY<=0.5000) & (Plumb7yrRandY>0.2333))
      {
        PlumbCostMean [4] = (80642.564 + 4.9662331*TSize)*TriDisModPlumbMean[3]
        PlumbCostMedian [4] = (86414.902 + 1.6289302*TSize)*TriDisModPlumbMedian[3]
      } else
      {
        PlumbCostMean [4] = 0
        PlumbCostMedian [4] = 0
      }
    } else
    {
      PlumbCostMean [4] = 0
      PlumbCostMedian [4] = 0
    }
    '----Facility Addition'
    'If statement determines if modification occurred it the set time period'
    if(Add19yrRandP<ModP_Add_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Add19yrRandY<=0.2593) & (Add19yrRandY>0.2593))
      {
        'Random selection of addition size based on weibull distro'
        AddSize = rweibull(1, shape = 1.3062133, scale = 1742.5275)
        'Updates the facility size for a potential facility lifecycle'
        TSize = TSize + AddSize
        'Set logic statements to the new facility size'
        '-Standard Size less than 9K but greater than 4k'
        SizeLE9K    = if(TSize<=4000)    {0} else if (TSize<=9000) {1} else {0}
        'Updates modification that change when addition occurs'
        '-Standard Size'
        ModP_HVAC_19  = exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9K+3.95959468
*Code121+1.93840929*ModP_HVAC_7)/(1+exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9
K+3.95959468*Code121+1.93840929*ModP_HVAC_7))
        ModP_COMM_19  = exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeLE9K+3.8671011
5*Code675+2.21037167*ModP_COMM_8)/(1+exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeL
E9K+3.86710115*Code675+2.21037167*ModP_COMM_8))
        'Determines addition Cost for average flexible and robust designs'
        'Recodes the cost of the addition based on size and number of stories'
        if(AddSize <= 2000)
        {
          if(NbrStories == 1)
```

```
          {
            AddCost [4] = (587770.49 + 255.30046*AddSize - 0.0342524*(AddSize-1100)^2)*Tr
iDisModStdAddStd[3]
            if(TSize>TASize)
            {
              FlexAvgAddCost [4]   = (587770.49 + 255.30046*(TSize-TASize) - 0.0342524*((
TSize-TASize)-1100)^2 )*TriDisModStdAddStd[3]
              FlexAvgAddCost [4]   = FlexAvgAddCost [4] + (102596.39 + 96.037325*(AddSize
-TSize+TASize) - 0.0293642*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[3]
              RobustAvgAddCost [4] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSiz
e-1100)^2)*TriDisModStdAddStd[3]
            }else
            {
              FlexAvgAddCost [4]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize)
-1100)^2)*TriDisModStdAddFlex[3]
              RobustAvgAddCost [4] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
            if(TSize>TMSize)
            {
              FlexMaxAddCost [4]   = (587770.49 + 255.30046*(TSize-TMSize) - 0.0342524*((
TSize-TMSize)-1100)^2)*TriDisModStdAddStd[3]
              FlexMaxAddCost [4]   = FlexMaxAddCost [4] + (102596.39 + 96.037325*(AddSize
-TSize+TMSize) - 0.0293642*((AddSize-TSize+TMSize)-1100)^2)*TriDisModStdAddFlex[3]
              RobustMaxAddCost [4] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSiz
e-1100)^2)*TriDisModStdAddStd[3]
            }else
            {
              FlexMaxAddCost [4]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize)
-1100)^2)*TriDisModStdAddFlex[3]
              RobustMaxAddCost [4] = 0
            }
          } else
          {
            AddCost [4] = (762491.78 + 294.13388*AddSize - 0.0289768*(AddSize-1100)^2)*Tr
iDisModStdAddStd[3]

            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {
              FlexAvgAddCost [4]   = (762491.78 + 294.13388*(TSize-TASize) - 0.0289768*((
TSize-TASize)-1100)^2)*TriDisModStdAddStd[3]
              FlexAvgAddCost [4]   = FlexAvgAddCost [4] + (120923.57 + 119.31587*(AddSize
-TSize+TASize) - 0.022339*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[3]
              RobustAvgAddCost [4] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSiz
e-1100)^2)*TriDisModStdAddStd[3]
            }else
```

```
            {
              FlexAvgAddCost [4]   = (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSiz
e)-1100)^2)*TriDisModStdAddFlex[3]
              RobustAvgAddCost [4] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
            if(TSize>TMSize)
            {
              FlexMaxAddCost [4]   = (762491.78 + 294.13388*(TSize-TMSize) - 0.0289768*((
TSize-TMSize)-1100)^2 )*TriDisModStdAddStd[3]
              FlexMaxAddCost [4]   = FlexMaxAddCost [4] + (120923.57 + 119.31587*(AddSize
-TSize+TMSize) - 0.022339*((AddSize-TSize+TMSize)-1100)^2 )*TriDisModStdAddFlex[3]
              RobustMaxAddCost [4] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSiz
e-1100)^2)*TriDisModStdAddStd[3]
            }else
            {
              FlexMaxAddCost [4]= (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSize)-
1100)^2)*TriDisModStdAddFlex[3]
              RobustMaxAddCost [4] = 0
            }
          }
        } else
        {
          AddCost [4] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[3]

          'Determines addition Cost for average flexible and robust designs'
          if(TSize>TASize)
          {
            FlexAvgAddCost [4]   = (841127.96 + 208.01641*(TSize-TASize) - 0.0001798*((TS
ize-TASize)-27413.8)^2 + 0.0000000010082*((TSize-TASize)-27413.8)^3)*TriDisModStdAddStd[3
]
            FlexAvgAddCost [4]   = FlexAvgAddCost [4] + (748729.11 + 267.12747*(AddSize-T
Size+TASize))*TriDisModStdAddFlex[3]
            RobustAvgAddCost [4] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[3]
          }else
          {
            FlexAvgAddCost [4]   = (748729.11 + 267.12747*AddSize)*TriDisModStdAddFlex[3]
            RobustAvgAddCost [4] = 0
          }
          'Determines addition Cost for max flexible and robust designs'
          if(TSize>TMSize)
          {
            FlexMaxAddCost [4]   = (841127.96 + 208.01641*(TSize-TMSize) - 0.0001798*((TS
ize-TMSize)-27413.8)^2 + 0.0000000010082*((TSize-TMSize)-27413.8)^3)*TriDisModStdAddStd[3
]
            FlexMaxAddCost [4]   = FlexMaxAddCost [4] + (727335.73 + 308.56524*(AddSize-T
Size+TMSize) - 0.000058747*((AddSize-TSize+TMSize)-27413.8)^2)*TriDisModStdAddFlex[3]
```

```
            RobustMaxAddCost [4] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[3]
          }else
          {
            FlexMaxAddCost [4]   = (727335.73 + 308.56524*(AddSize) - 0.000058747*((AddSi
ze)-27413.8)^2)*TriDisModStdAddFlex[3]
            RobustMaxAddCost [4] = 0
          }
        }
      } else
      {
        AddCost [4] = 0
        FlexAvgAddCost [4] = 0
        FlexMaxAddCost [4] = 0
        RobustAvgAddCost [4] = 0
        RobustMaxAddCost [4] = 0
      }
    } else
    {
      AddCost [4] = 0
      FlexAvgAddCost [4] = 0
      FlexMaxAddCost [4] = 0
      RobustAvgAddCost [4] = 0
      RobustMaxAddCost [4] = 0
    }

    '- Year 4 Predicted Costs'
    '---Annual operational costs for each facility Size'
    if(TSize<9000)
    {
      OpCost [5]     = (26712.066 + 10.191641*TSize)*TriDisOpYr04
      AvgOpCost [5]  = (26712.066 + 10.191641*TASize)*TriDisOpYr04
      MaxOpCost [5]  = (26712.066 + 10.191641*TMSize)*TriDisOpYr04
    } else
    {
      OpCost [5]     = (67787.387 + 9.6105233*TSize)*TriDisOpYr04
      AvgOpCost [5]  = (67787.387 + 9.6105233*TASize)*TriDisOpYr04
      MaxOpCost [5]  = (67787.387 + 9.6105233*TMSize)*TriDisOpYr04
    }

    '---Modifications predicted in Lifecycle and their costs'
    '----HVAC Modification'
    'If statement determines if modification occurred it the set time period'
    if(HVAC7yrRandP<ModP_HVAC_7)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((HVAC7yrRandY<=0.5385) & (HVAC7yrRandY>0.3846))
```

```
      {
        if(NbrStories == 1)
        {
          HVACCostMean [5] = (171399.41 + 17.39759*TSize)*TriDisModHVACMean[4]
          HVACCostMedian [5] = (154855.44 + 3.81795606*TSize)*TriDisModHVACMedian[4]
        }
        else
        {
          HVACCostMean [5] = (196252.41 + 17.839797*TSize)*TriDisModHVACMean[4]
          HVACCostMedian [5] = (156490.77 + 3.9482492*TSize)*TriDisModHVACMedian[4]
        }

      } else
      {
        HVACCostMean [5] = 0
        HVACCostMedian [5] = 0
      }
    } else
    {
      HVACCostMean [5] = 0
      HVACCostMedian [5] = 0
    }
    '----COMM Modification'
    'If statement determines if modification occurred it the set time period'
    if(COMM4yrRandP<ModP_COMM_4)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((COMM4yrRandY<=1) & (COMM4yrRandY>0.7241))
      {
        COMMCostMean [5] = (80771.311 + 7.2269841*TSize)*TriDisModCOMMMean[4]
        COMMCostMedian [5] = (85440.873 + 3.1165737*TSize)*TriDisModCOMMMedian[4]

      } else
      {
        COMMCostMean [5] = 0
        COMMCostMedian [5] = 0
      }
    }else
    {
      COMMCostMean [5] = 0
      COMMCostMedian [5] = 0
    }
    '----Electrical Modification'
    'If statement determines if modification occurred it the set time period'
    if(Elect6yrRandP<ModP_Elect_6)
    {
```

```
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Elect6yrRandY<=0.8333) & (Elect6yrRandY>0.7143))
      {
        ElectCostMean [5] = (72737.512 + 9.3469036*TSize)*TriDisModElectricMean[4]
        ElectCostMedian [5] = (76229.68 + 6.4750386*TSize)*TriDisModElectricMedian[4]
      } else
      {
        ElectCostMean [5] = 0
        ElectCostMedian [5] = 0
      }
    }else
    {
      ElectCostMean [5] = 0
      ElectCostMedian [5] = 0
    }
    '----Plumbing Modification'
    'If statement determines if modification occurred it the set time period'
    if(Plumb7yrRandP<ModP_Plumb_7)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Plumb7yrRandY<=0.6000) & (Plumb7yrRandY>0.5000))
      {
        PlumbCostMean [5] = (80642.564 + 4.9662331*TSize)*TriDisModPlumbMean[4]
        PlumbCostMedian [5] = (86414.902 + 1.6289302*TSize)*TriDisModPlumbMedian[4]
      } else
      {
        PlumbCostMean [5] = 0
        PlumbCostMedian [5] = 0
      }
    } else
    {
      PlumbCostMean [5] = 0
      PlumbCostMedian [5] = 0
    }
    '----Facility Addition'
    'If statement determines if modification occurred it the set time period'
    if(Add19yrRandP<ModP_Add_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Add19yrRandY<=0.3333) & (Add19yrRandY>0.2593))
      {
        'Random selection of addition size based on weibull distro'
        AddSize = rweibull(1, shape = 1.3062133, scale = 1742.5275)
        'Updates the facility size for a potential facility lifecycle'
```

```
        TSize = TSize + AddSize
        'Set logic statements to the new facility size'
        '-Standard Size less than 9K but greater than 4k'
        SizeLE9K    = if(TSize<=4000)    {0} else if (TSize<=9000) {1} else {0}
        'Updates modification that change when addition occurs'
        '-Standard Size'
        ModP_HVAC_19  = exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9K+3.95959468
*Code121+1.93840929*ModP_HVAC_7)/(1+exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9
K+3.95959468*Code121+1.93840929*ModP_HVAC_7))
        ModP_COMM_19  = exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeLE9K+3.8671011
5*Code675+2.21037167*ModP_COMM_8)/(1+exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeL
E9K+3.86710115*Code675+2.21037167*ModP_COMM_8))
        'Recodes the cost of the addition based on size and number of stories'
        if(AddSize <= 2000)
        {
          if(NbrStories == 1)
          {
            AddCost [5] = (587770.49 + 255.30046*AddSize - 0.0342524*(AddSize-1100)^2)*Tr
iDisModStdAddStd[4]

            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {
              FlexAvgAddCost [5]   = (587770.49 + 255.30046*(TSize-TASize) - 0.0342524*((
TSize-TASize)-1100)^2 )*TriDisModStdAddStd[4]
              FlexAvgAddCost [5]   = FlexAvgAddCost [5] + (102596.39 + 96.037325*(AddSize
-TSize+TASize) - 0.0293642*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[4]
              RobustAvgAddCost [5] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSiz
e-1100)^2)*TriDisModStdAddStd[4]
            }else
            {
              FlexAvgAddCost [5]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize)
-1100)^2)*TriDisModStdAddFlex[4]
              RobustAvgAddCost [5] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
            if(TSize>TMSize)
            {
              FlexMaxAddCost [5]   = (587770.49 + 255.30046*(TSize-TMSize) - 0.0342524*((
TSize-TMSize)-1100)^2)*TriDisModStdAddStd[4]
              FlexMaxAddCost [5]   = FlexMaxAddCost [5] + (102596.39 + 96.037325*(AddSize
-TSize+TMSize) - 0.0293642*((AddSize-TSize+TMSize)-1100)^2)*TriDisModStdAddFlex[4]
              RobustMaxAddCost [5] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSiz
e-1100)^2)*TriDisModStdAddStd[4]
            }else
            {
              FlexMaxAddCost [5]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize)
```

```
-1100)^2)*TriDisModStdAddFlex[4]
              RobustMaxAddCost [5] = 0
            }
          } else
          {
            AddCost [5] = (762491.78 + 294.13388*AddSize - 0.0289768*(AddSize-1100)^2)*Tr
iDisModStdAddStd[4]

            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {
              FlexAvgAddCost [5]   = (762491.78 + 294.13388*(TSize-TASize) - 0.0289768*((
TSize-TASize)-1100)^2)*TriDisModStdAddStd[4]
              FlexAvgAddCost [5]   = FlexAvgAddCost [5] + (120923.57 + 119.31587*(AddSize
-TSize+TASize) - 0.022339*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[4]
              RobustAvgAddCost [5] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSiz
e-1100)^2)*TriDisModStdAddStd[4]
            }else
            {
              FlexAvgAddCost [5]   = (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSiz
e)-1100)^2)*TriDisModStdAddFlex[4]
              RobustAvgAddCost [5] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
            if(TSize>TMSize)
            {
              FlexMaxAddCost [5]   = (762491.78 + 294.13388*(TSize-TMSize) - 0.0289768*((
TSize-TMSize)-1100)^2 )*TriDisModStdAddStd[4]
              FlexMaxAddCost [5]   = FlexMaxAddCost [5] + (120923.57 + 119.31587*(AddSize
-TSize+TMSize) - 0.022339*((AddSize-TSize+TMSize)-1100)^2 )*TriDisModStdAddFlex[4]
              RobustMaxAddCost [5] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSiz
e-1100)^2)*TriDisModStdAddStd[4]
            }else
            {
              FlexMaxAddCost [5]= (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSize)-
1100)^2)*TriDisModStdAddFlex[4]
              RobustMaxAddCost [5] = 0
            }
          }
        } else
        {
          AddCost [5] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[4]

          'Determines addition Cost for average flexible and robust designs'
          if(TSize>TASize)
          {
            FlexAvgAddCost [5]   = (841127.96 + 208.01641*(TSize-TASize) - 0.0001798*((TS
```

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ize-TASize)-27413.8)^2 + 0.0000000010082*((TSize-TASize)-27413.8)^3)*TriDisModStdAddStd[4
]
            FlexAvgAddCost [5]   = FlexAvgAddCost [5] + (748729.11 + 267.12747*(AddSize-T
Size+TASize))*TriDisModStdAddFlex[4]
            RobustAvgAddCost [5] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[4]
          }else
          {
            FlexAvgAddCost [5]   = (748729.11 + 267.12747*AddSize)*TriDisModStdAddFlex[4]
            RobustAvgAddCost [5] = 0
          }
          'Determines addition Cost for max flexible and robust designs'
          if(TSize>TMSize)
          {
            FlexMaxAddCost [5]   = (841127.96 + 208.01641*(TSize-TMSize) - 0.0001798*((TS
ize-TMSize)-27413.8)^2 + 0.0000000010082*((TSize-TMSize)-27413.8)^3)*TriDisModStdAddStd[4
]
            FlexMaxAddCost [5]   = FlexMaxAddCost [5] + (727335.73 + 308.56524*(AddSize-T
Size+TMSize) - 0.000058747*((AddSize-TSize+TMSize)-27413.8)^2)*TriDisModStdAddFlex[4]
            RobustMaxAddCost [5] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[4]
          }else
          {
            FlexMaxAddCost [5]   = (727335.73 + 308.56524*(AddSize) - 0.000058747*((AddSi
ze)-27413.8)^2)*TriDisModStdAddFlex[4]
            RobustMaxAddCost [5] = 0
          }
        }
      } else
      {
        AddCost [5] = 0
        FlexAvgAddCost [5] = 0
        FlexMaxAddCost [5] = 0
        RobustAvgAddCost [5] = 0
        RobustMaxAddCost [5] = 0
      }
    } else
    {
      AddCost [5] = 0
      FlexAvgAddCost [5] = 0
      FlexMaxAddCost [5] = 0
      RobustAvgAddCost [5] = 0
      RobustMaxAddCost [5] = 0
    }

    '- Year 5 Predicted Costs'
    '---Annual operational costs for each facility Size'
    if(TSize<9000)
    {
```

```
      OpCost [6]     = (22713.059 +  11.239182*TSize)*TriDisOpYr05
      AvgOpCost [6]  = (22713.059 +  11.239182*TASize)*TriDisOpYr05
      MaxOpCost [6]  = (22713.059 +  11.239182*TMSize)*TriDisOpYr05
    } else
    {
      OpCost [6]     = (78682.76 + 9.6097858*TSize)*TriDisOpYr05
      AvgOpCost [6]  = (78682.76 + 9.6097858*TASize)*TriDisOpYr05
      MaxOpCost [6]  = (78682.76 + 9.6097858*TMSize)*TriDisOpYr05
    }

    '---Modifications predicted in Lifecycle and their costs'
    '----HVAC Modification'
    'If statement determines if modification occurred it the set time period'
    if(HVAC7yrRandP<ModP_HVAC_7)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((HVAC7yrRandY<=0.6154) & (HVAC7yrRandY>0.5385))
      {
        if(NbrStories == 1)
        {
          HVACCostMean [6] = (171399.41 + 17.39759*TSize)*TriDisModHVACMean[5]
          HVACCostMedian [6] = (154855.44 + 3.81795606*TSize)*TriDisModHVACMedian[5]
        }
        else
        {
          HVACCostMean [6] = (196252.41 + 17.839797*TSize)*TriDisModHVACMean[5]
          HVACCostMedian [6] = (156490.77 + 3.9482492*TSize)*TriDisModHVACMedian[5]
        }

      } else
      {
        HVACCostMean [6] = 0
        HVACCostMedian [6] = 0
      }
    } else
    {
      HVACCostMean [6] = 0
      HVACCostMedian [6] = 0
    }
    '----COMM Modification'
    'Random variable used to determine what year modification occured'
    COMM8yrRandP = runif(1, min = 0, max = 1) # P = Period of modification
    COMM8yrRandY = runif(1, min = 0, max = 1) # Y = Year of modification
    'If statement determines if modification occurred it the set time period'
    if(COMM8yrRandP<ModP_COMM_8)
    {
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```
      'If Statement determines if the modification occured in this year and records the c
ost'
      if(COMM8yrRandY<=0.2800)
      {
        COMMCostMean [6] = (80771.311 + 7.2269841*TSize)*TriDisModCOMMMean[6]
        COMMCostMedian [6] = (85440.873 + 3.1165737*TSize)*TriDisModCOMMMedian[6]

      } else
      {
        COMMCostMean [6] = 0
        COMMCostMedian [6] = 0
      }
    }else
    {
      COMMCostMean [6] = 0
      COMMCostMedian [6] = 0
    }
    '----Electrical Modification'
    'If statement determines if modification occurred it the set time period'
    if(Elect6yrRandP<ModP_Elect_6)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Elect6yrRandY<=0.9286) & (Elect6yrRandY>0.8333))
      {
        ElectCostMean [6] = (72737.512 + 9.3469036*TSize)*TriDisModElectricMean[5]
        ElectCostMedian [6] = (76229.68 + 6.4750386*TSize)*TriDisModElectricMedian[5]
      } else
      {
        ElectCostMean [6] = 0
        ElectCostMedian [6] = 0
      }
    }else
    {
      ElectCostMean [6] = 0
      ElectCostMedian [6] = 0
    }
    '----Plumbing Modification'
    'If statement determines if modification occurred it the set time period'
    if(Plumb7yrRandP<ModP_Plumb_7)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Plumb7yrRandY<=0.7667) & (Plumb7yrRandY>0.6000))
      {
        PlumbCostMean [6] = (80642.564 + 4.9662331*TSize)*TriDisModPlumbMean[5]
        PlumbCostMedian [6] = (86414.902 + 1.6289302*TSize)*TriDisModPlumbMedian[5]
```

```
      } else
      {
        PlumbCostMean [6] = 0
        PlumbCostMedian [6] = 0
      }
    } else
    {
      PlumbCostMean [6] = 0
      PlumbCostMedian [6] = 0
    }
    '----Facility Addition'
    'If statement determines if modification occurred it the set time period'
    if(Add19yrRandP<ModP_Add_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Add19yrRandY<=0.4074) & (Add19yrRandY>0.3333))
      {
        'Random selection of addition size based on weibull distro'
        AddSize = rweibull(1, shape = 1.3062133, scale = 1742.5275)
        'Updates the facility size for a potential facility lifecycle'
        TSize = TSize + AddSize
        'Set logic statements to the new facility size'
        '-Standard Size less than 9K but greater than 4k'
        SizeLE9K    = if(TSize<=4000)    {0} else if (TSize<=9000) {1} else {0}
        'Updates modification that change when addition occurs'
        '-Standard Size'
        ModP_HVAC_19  = exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9K+3.95959468
*Code121+1.93840929*ModP_HVAC_7)/(1+exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9
K+3.95959468*Code121+1.93840929*ModP_HVAC_7))
        ModP_COMM_19  = exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeLE9K+3.8671011
5*Code675+2.21037167*ModP_COMM_8)/(1+exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeL
E9K+3.86710115*Code675+2.21037167*ModP_COMM_8))
        'Recodes the cost of the addition based on size and number of stories'
        if(AddSize <= 2000)
        {
          if(NbrStories == 1)
          {
            AddCost [6] = (587770.49 + 255.30046*AddSize - 0.0342524*(AddSize-1100)^2)*Tr
iDisModStdAddStd[5]

            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {
              FlexAvgAddCost [6]   = (587770.49 + 255.30046*(TSize-TASize) - 0.0342524*((
TSize-TASize)-1100)^2 )*TriDisModStdAddStd[5]
              FlexAvgAddCost [6]   = FlexAvgAddCost [6] + (102596.39 + 96.037325*(AddSize
```

```
-TSize+TASize) - 0.0293642*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[5]
              RobustAvgAddCost [6] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSiz
e-1100)^2)*TriDisModStdAddStd[5]
            }else
            {
              FlexAvgAddCost [6]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize)
-1100)^2)*TriDisModStdAddFlex[5]
              RobustAvgAddCost [6] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
            if(TSize>TMSize)
            {
              FlexMaxAddCost [6]   = (587770.49 + 255.30046*(TSize-TMSize) - 0.0342524*((
TSize-TMSize)-1100)^2)*TriDisModStdAddStd[5]
              FlexMaxAddCost [6]   = FlexMaxAddCost [6] + (102596.39 + 96.037325*(AddSize
-TSize+TMSize) - 0.0293642*((AddSize-TSize+TMSize)-1100)^2)*TriDisModStdAddFlex[5]
              RobustMaxAddCost [6] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSiz
e-1100)^2)*TriDisModStdAddStd[5]
            }else
            {
              FlexMaxAddCost [6]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize)
-1100)^2)*TriDisModStdAddFlex[5]
              RobustMaxAddCost [6] = 0
            }
          } else
          {
            AddCost [6] = (762491.78 + 294.13388*AddSize - 0.0289768*(AddSize-1100)^2)*Tr
iDisModStdAddStd[5]

            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {
              FlexAvgAddCost [6]   = (762491.78 + 294.13388*(TSize-TASize) - 0.0289768*((
TSize-TASize)-1100)^2)*TriDisModStdAddStd[5]
              FlexAvgAddCost [6]   = FlexAvgAddCost [6] + (120923.57 + 119.31587*(AddSize
-TSize+TASize) - 0.022339*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[5]
              RobustAvgAddCost [6] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSiz
e-1100)^2)*TriDisModStdAddStd[5]
            }else
            {
              FlexAvgAddCost [6]   = (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSiz
e)-1100)^2)*TriDisModStdAddFlex[5]
              RobustAvgAddCost [6] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
            if(TSize>TMSize)
            {
```

```
              FlexMaxAddCost [6]   = (762491.78 + 294.13388*(TSize-TMSize) - 0.0289768*((
TSize-TMSize)-1100)^2 )*TriDisModStdAddStd[5]
              FlexMaxAddCost [6]   = FlexMaxAddCost [6] + (120923.57 + 119.31587*(AddSize
-TSize+TMSize) - 0.022339*((AddSize-TSize+TMSize)-1100)^2 )*TriDisModStdAddFlex[5]
              RobustMaxAddCost [6] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSiz
e-1100)^2)*TriDisModStdAddStd[5]
            }else
            {
              FlexMaxAddCost [6]= (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSize)-
1100)^2)*TriDisModStdAddFlex[5]
              RobustMaxAddCost [6] = 0
            }
          }
        } else
        {
          AddCost [6] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[5]

          'Determines addition Cost for average flexible and robust designs'
          if(TSize>TASize)
          {
            FlexAvgAddCost [6]   = (841127.96 + 208.01641*(TSize-TASize) - 0.0001798*((TS
ize-TASize)-27413.8)^2 + 0.0000000010082*((TSize-TASize)-27413.8)^3)*TriDisModStdAddStd[5
]
            FlexAvgAddCost [6]   = FlexAvgAddCost [6] + (748729.11 + 267.12747*(AddSize-T
Size+TASize))*TriDisModStdAddFlex[5]
            RobustAvgAddCost [6] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[5]
          }else
          {
            FlexAvgAddCost [6]   = (748729.11 + 267.12747*AddSize)*TriDisModStdAddFlex[5]
            RobustAvgAddCost [6] = 0
          }
          'Determines addition Cost for max flexible and robust designs'
          if(TSize>TMSize)
          {
            FlexMaxAddCost [6]   = (841127.96 + 208.01641*(TSize-TMSize) - 0.0001798*((TS
ize-TMSize)-27413.8)^2 + 0.0000000010082*((TSize-TMSize)-27413.8)^3)*TriDisModStdAddStd[5
]
            FlexMaxAddCost [6]   = FlexMaxAddCost [6] + (727335.73 + 308.56524*(AddSize-T
Size+TMSize) - 0.000058747*((AddSize-TSize+TMSize)-27413.8)^2)*TriDisModStdAddFlex[5]
            RobustMaxAddCost [6] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[5]
          }else
          {
            FlexMaxAddCost [6]   = (727335.73 + 308.56524*(AddSize) - 0.000058747*((AddSi
ze)-27413.8)^2)*TriDisModStdAddFlex[5]
            RobustMaxAddCost [6] = 0
          }
        }
```

```
      } else
      {
        AddCost [6] = 0
        FlexAvgAddCost [6] = 0
        FlexMaxAddCost [6] = 0
        RobustAvgAddCost [6] = 0
        RobustMaxAddCost [6] = 0
      }
    } else
    {
      AddCost [6] = 0
      FlexAvgAddCost [6] = 0
      FlexMaxAddCost [6] = 0
      RobustAvgAddCost [6] = 0
      RobustMaxAddCost [6] = 0
    }

    '- Year 6 Predicted Costs'
    '---Annual operational costs for each facility Size'
    if(TSize<9000)
    {
      OpCost [7]     = (22748.417 + 11.277431*TSize)*TriDisOpYr06
      AvgOpCost [7]  = (22748.417 + 11.277431*TASize)*TriDisOpYr06
      MaxOpCost [7]  = (22748.417 + 11.277431*TMSize )*TriDisOpYr06
    } else
    {
      OpCost [7]     = (78682.76 + 9.6097858*TSize)*TriDisOpYr06
      AvgOpCost [7]  = (78682.76 + 9.6097858*TASize)*TriDisOpYr06
      MaxOpCost [7]  = (78682.76 + 9.6097858*TMSize)*TriDisOpYr06
    }

    '---Modifications predicted in Lifecycle and their costs'
    '----HVAC Modification'
    'If statement determines if modification occurred it the set time period'
    if(HVAC7yrRandP<ModP_HVAC_7)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((HVAC7yrRandY<=0.8462) & (HVAC7yrRandY>0.6154))
      {
        if(NbrStories == 1)
        {
          HVACCostMean [7] = (171399.41 + 17.39759*TSize)*TriDisModHVACMean[6]
          HVACCostMedian [7] = (154855.44 + 3.81795606*TSize)*TriDisModHVACMedian[6]
        }
        else
        {
```

```
          HVACCostMean [7] = (196252.41 + 17.839797*TSize)*TriDisModHVACMean[6]
          HVACCostMedian [7] = (156490.77 + 3.9482492*TSize)*TriDisModHVACMedian[6]
        }

      } else
      {
        HVACCostMean [7] = 0
        HVACCostMedian [7] = 0
      }
    } else
    {
      HVACCostMean [7] = 0
      HVACCostMedian [7] = 0
    }
    '----COMM Modification'
    'If statement determines if modification occurred it the set time period'
    if(COMM8yrRandP<ModP_COMM_8)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((COMM8yrRandY<=0.4800) & (COMM8yrRandY>0.2800))
      {
        COMMCostMean [7] = (80771.311 + 7.2269841*TSize)*TriDisModCOMMMean[6]
        COMMCostMedian [7] = (85440.873 + 3.1165737*TSize)*TriDisModCOMMMedian[6]
      } else
      {
        COMMCostMean [7] = 0
        COMMCostMedian [7] = 0
      }
    }else
    {
      COMMCostMean [7] = 0
      COMMCostMedian [7] = 0
    }
    '----Electrical Modification'
    'If statement determines if modification occurred it the set time period'
    if(Elect6yrRandP<ModP_Elect_6)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Elect6yrRandY<=1) & (Elect6yrRandY>0.9286))
      {
        ElectCostMean [7] = (72737.512 + 9.3469036*TSize)*TriDisModElectricMean[6]
        ElectCostMedian [7] = (76229.68 + 6.4750386*TSize)*TriDisModElectricMedian[6]
      } else
      {
        ElectCostMean [7] = 0
```

```
        ElectCostMedian [7] = 0
      }
    }else
    {
      ElectCostMean [7] = 0
      ElectCostMedian [7] = 0
    }
    '----Plumbing Modification'
    'If statement determines if modification occurred it the set time period'
    if(Plumb7yrRandP<ModP_Plumb_7)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Plumb7yrRandY<=0.8667) & (Plumb7yrRandY>0.7667))
      {
        PlumbCostMean [7] = (80642.564 + 4.9662331*TSize)*TriDisModPlumbMean[6]
        PlumbCostMedian [7] = (86414.902 + 1.6289302*TSize)*TriDisModPlumbMedian[6]
      } else
      {
        PlumbCostMean [7] = 0
        PlumbCostMedian [7] = 0
      }
    } else
    {
      PlumbCostMean [7] = 0
      PlumbCostMedian [7] = 0
    }
    '----Facility Addition'
    'If statement determines if modification occurred it the set time period'
    if(Add19yrRandP<ModP_Add_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Add19yrRandY<=0.5556) & (Add19yrRandY>0.4074))
      {
        'Random selection of addition size based on weibull distro'
        AddSize = rweibull(1, shape = 1.3062133, scale = 1742.5275)
        'Updates the facility size for a potential facility lifecycle'
        TSize = TSize + AddSize
        'Set logic statements to the new facility size'
        '-Standard Size less than 9K but greater than 4k'
        SizeLE9K    = if(TSize<=4000)    {0} else if (TSize<=9000) {1} else {0}
        'Updates modification that change when addition occurs'
        '-Standard Size'
        ModP_HVAC_19  = exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9K+3.95959468
*Code121+1.93840929*ModP_HVAC_7)/(1+exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9
K+3.95959468*Code121+1.93840929*ModP_HVAC_7))
```

```
        ModP_COMM_19  = exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeLE9K+3.8671011
5*Code675+2.21037167*ModP_COMM_8)/(1+exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeL
E9K+3.86710115*Code675+2.21037167*ModP_COMM_8))
        'Recodes the cost of the addition based on size and number of stories'
        if(AddSize <= 2000)
        {
          if(NbrStories == 1)
          {
            AddCost [7] = (587770.49 + 255.30046*AddSize - 0.0342524*(AddSize-1100)^2)*Tr
iDisModStdAddStd[6]

            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {
              FlexAvgAddCost [7]   = (587770.49 + 255.30046*(TSize-TASize) - 0.0342524*((
TSize-TASize)-1100)^2 )*TriDisModStdAddStd[6]
              FlexAvgAddCost [7]   = FlexAvgAddCost [7] + (102596.39 + 96.037325*(AddSize
-TSize+TASize) - 0.0293642*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[6]
              RobustAvgAddCost [7] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSiz
e-1100)^2)*TriDisModStdAddStd[6]
            }else
            {
              FlexAvgAddCost [7]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize)
-1100)^2)*TriDisModStdAddFlex[6]
              RobustAvgAddCost [7] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
            if(TSize>TMSize)
            {
              FlexMaxAddCost [7]   = (587770.49 + 255.30046*(TSize-TMSize) - 0.0342524*((
TSize-TMSize)-1100)^2)*TriDisModStdAddStd[6]
              FlexMaxAddCost [7]   = FlexMaxAddCost [7] + (102596.39 + 96.037325*(AddSize
-TSize+TMSize) - 0.0293642*((AddSize-TSize+TMSize)-1100)^2)*TriDisModStdAddFlex[6]
              RobustMaxAddCost [7] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSiz
e-1100)^2)*TriDisModStdAddStd[6]
            }else
            {
              FlexMaxAddCost [7]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize)
-1100)^2)*TriDisModStdAddFlex[6]
              RobustMaxAddCost [7] = 0
            }
          } else
          {
            AddCost [7] = (762491.78 + 294.13388*AddSize - 0.0289768*(AddSize-1100)^2)*Tr
iDisModStdAddStd[6]

            'Determines addition Cost for average flexible and robust designs'
```

```
            if(TSize>TASize)
            {
              FlexAvgAddCost [7]   = (762491.78 + 294.13388*(TSize-TASize) - 0.0289768*((
TSize-TASize)-1100)^2)*TriDisModStdAddStd[6]
              FlexAvgAddCost [7]   = FlexAvgAddCost [7] + (120923.57 + 119.31587*(AddSize
-TSize+TASize) - 0.022339*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[6]
              RobustAvgAddCost [7] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSiz
e-1100)^2)*TriDisModStdAddStd[6]
            }else
            {
              FlexAvgAddCost [7]   = (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSiz
e)-1100)^2)*TriDisModStdAddFlex[6]
              RobustAvgAddCost [7] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
            if(TSize>TMSize)
            {
              FlexMaxAddCost [7]   = (762491.78 + 294.13388*(TSize-TMSize) - 0.0289768*((
TSize-TMSize)-1100)^2 )*TriDisModStdAddStd[6]
              FlexMaxAddCost [7]   = FlexMaxAddCost [7] + (120923.57 + 119.31587*(AddSize
-TSize+TMSize) - 0.022339*((AddSize-TSize+TMSize)-1100)^2 )*TriDisModStdAddFlex[6]
              RobustMaxAddCost [7] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSiz
e-1100)^2)*TriDisModStdAddStd[6]
            }else
            {
              FlexMaxAddCost [7]= (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSize)-
1100)^2)*TriDisModStdAddFlex[6]
              RobustMaxAddCost [7] = 0
            }
          }
        } else
        {
          AddCost [7] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[6]

          'Determines addition Cost for average flexible and robust designs'
          if(TSize>TASize)
          {
            FlexAvgAddCost [7]   = (841127.96 + 208.01641*(TSize-TASize) - 0.0001798*((TS
ize-TASize)-27413.8)^2 + 0.0000000010082*((TSize-TASize)-27413.8)^3)*TriDisModStdAddStd[6
]
            FlexAvgAddCost [7]   = FlexAvgAddCost [7] + (748729.11 + 267.12747*(AddSize-T
Size+TASize))*TriDisModStdAddFlex[6]
            RobustAvgAddCost [7] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[6]
          }else
          {
            FlexAvgAddCost [7]   = (748729.11 + 267.12747*AddSize)*TriDisModStdAddFlex[6]
            RobustAvgAddCost [7] = 0
```

```
          }
          'Determines addition Cost for max flexible and robust designs'
          if(TSize>TMSize)
          {
            FlexMaxAddCost [7]   = (841127.96 + 208.01641*(TSize-TMSize) - 0.0001798*((TSize-TMSize)-27413.8)^2 + 0.0000000010082*((TSize-TMSize)-27413.8)^3)*TriDisModStdAddStd[6]
            FlexMaxAddCost [7]   = FlexMaxAddCost [7] + (727335.73 + 308.56524*(AddSize-TSize+TMSize) - 0.000058747*((AddSize-TSize+TMSize)-27413.8)^2)*TriDisModStdAddFlex[6]
            RobustMaxAddCost [7] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[6]
          }else
          {
            FlexMaxAddCost [7]   = (727335.73 + 308.56524*(AddSize) - 0.000058747*((AddSize)-27413.8)^2)*TriDisModStdAddFlex[6]
            RobustMaxAddCost [7] = 0
          }
        }
      } else
      {
        AddCost [7] = 0
        FlexAvgAddCost [7] = 0
        FlexMaxAddCost [7] = 0
        RobustAvgAddCost [7] = 0
        RobustMaxAddCost [7] = 0
      }
    } else
    {
      AddCost [7] = 0
      FlexAvgAddCost [7] = 0
      FlexMaxAddCost [7] = 0
      RobustAvgAddCost [7] = 0
      RobustMaxAddCost [7] = 0
    }

    '- Year 7 Predicted Costs'
    '---Annual operational costs for each facility Size'
    if(TSize<9000)
    {
      OpCost [8]     = (22981.58 + 11.305378*TSize)*TriDisOpYr07
      AvgOpCost [8]  = (22981.58 + 11.305378*TASize)*TriDisOpYr07
      MaxOpCost [8]  = (22981.58 + 11.305378*TMSize)*TriDisOpYr07
    } else
    {
      OpCost [8]     = (72239.718 + 9.6393708*TSize)*TriDisOpYr07
      AvgOpCost [8]  = (72239.718 + 9.6393708*TASize)*TriDisOpYr07
      MaxOpCost [8]  = (72239.718 + 9.6393708*TMSize)*TriDisOpYr07
    }
```

```
'---Modifications predicted in Lifecycle and their costs'
'----HVAC Modification'
'If statement determines if modification occurred it the set time period'
if(HVAC7yrRandP<ModP_HVAC_7)
{
  'If Statement determines if the modification occured in this year and records the c
ost'
  if((HVAC7yrRandY<=1) & (HVAC7yrRandY>0.8462))
  {
    if(NbrStories == 1)
    {
      HVACCostMean [8] = (171399.41 + 17.39759*TSize)*TriDisModHVACMean[7]
      HVACCostMedian [8] = (154855.44 + 3.81795606*TSize)*TriDisModHVACMedian[7]
    }
    else
    {
      HVACCostMean [8] = (196252.41 + 17.839797*TSize)*TriDisModHVACMean[7]
      HVACCostMedian [8] = (156490.77 + 3.9482492*TSize)*TriDisModHVACMedian[7]
    }

  } else
  {
    HVACCostMean [8] = 0
    HVACCostMedian [8] = 0
  }
} else
{
  HVACCostMean [8] = 0
  HVACCostMedian [8] = 0
}
'----COMM Modification'
'If statement determines if modification occurred it the set time period'
if(COMM8yrRandP<ModP_COMM_8)
{
  'If Statement determines if the modification occured in this year and records the c
ost'
  if((COMM8yrRandY<=0.8800) & (COMM8yrRandY>0.4800))
  {
    COMMCostMean [8] = (80771.311 + 7.2269841*TSize)*TriDisModCOMMMean[7]
    COMMCostMedian [8] = (85440.873 + 3.1165737*TSize)*TriDisModCOMMMedian[7]
  } else
  {
    COMMCostMean [8] = 0
    COMMCostMedian [8] = 0
  }
}else
```

```
    {
      COMMCostMean [8] = 0
      COMMCostMedian [8] = 0
    }
    '----Electrical Modification'
    'Random variable used to determine what year modification occured'
    Elect19yrRandP = runif(1, min = 0, max = 1)
    Elect19yrRandY = runif(1, min = 0, max = 1)
    'If statement determines if modification occurred it the set time period'
    if(Elect19yrRandP<ModP_Elect_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if(Elect19yrRandY<=0.2414)
      {
        ElectCostMean [8] = (72737.512 + 9.3469036*TSize)*TriDisModElectricMean[7]
        ElectCostMedian [8] = (76229.68 + 6.4750386*TSize)*TriDisModElectricMedian[7]
      } else
      {
        ElectCostMean [8] = 0
        ElectCostMedian [8] = 0
      }
    }else
    {
      ElectCostMean [8] = 0
      ElectCostMedian [8] = 0
    }
    '----Plumbing Modification'
    'If statement determines if modification occurred it the set time period'
    if(Plumb7yrRandP<ModP_Plumb_7)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Plumb7yrRandY<=0.8500) & (Plumb7yrRandY>0.8667))
      {
        PlumbCostMean [8] = (80642.564 + 4.9662331*TSize)*TriDisModPlumbMean[7]
        PlumbCostMedian [8] = (86414.902 + 1.6289302*TSize)*TriDisModPlumbMedian[7]
      } else
      {
        PlumbCostMean [8] = 0
        PlumbCostMedian [8] = 0
      }
    } else
    {
      PlumbCostMean [8] = 0
      PlumbCostMedian [8] = 0
    }
```

```
    '----Facility Addition'
    'If statement determines if modification occurred it the set time period'
    if(Add19yrRandP<ModP_Add_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Add19yrRandY<=0.6296) & (Add19yrRandY>0.5556))
      {
        'Random selection of addition size based on weibull distro'
        AddSize = rweibull(1, shape = 1.3062133, scale = 1742.5275)
        'Updates the facility size for a potential facility lifecycle'
        TSize = TSize + AddSize
        'Set logic statements to the new facility size'
        '-Standard Size less than 9K but greater than 4k'
        SizeLE9K    = if(TSize<=4000)    {0} else if (TSize<=9000) {1} else {0}
        'Updates modification that change when addition occurs'
        '-Standard Size'
        ModP_HVAC_19  = exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9K+3.95959468
*Code121+1.93840929*ModP_HVAC_7)/(1+exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9
K+3.95959468*Code121+1.93840929*ModP_HVAC_7))
        ModP_COMM_19  = exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeLE9K+3.8671011
5*Code675+2.21037167*ModP_COMM_8)/(1+exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeL
E9K+3.86710115*Code675+2.21037167*ModP_COMM_8))
        'Recodes the cost of the addition based on size and number of stories'
        if(AddSize <= 2000)
        {
          if(NbrStories == 1)
          {
            AddCost [8] = (587770.49 + 255.30046*AddSize - 0.0342524*(AddSize-1100)^2)*Tr
iDisModStdAddStd[7]
            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {
              FlexAvgAddCost [8]   = (587770.49 + 255.30046*(TSize-TASize) - 0.0342524*((
TSize-TASize)-1100)^2 )*TriDisModStdAddStd[7]
              FlexAvgAddCost [8]   = FlexAvgAddCost [8] + (102596.39 + 96.037325*(AddSize
-TSize+TASize) - 0.0293642*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[7]
              RobustAvgAddCost [8] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSiz
e-1100)^2)*TriDisModStdAddStd[7]
            }else
            {
              FlexAvgAddCost [8]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize)
-1100)^2)*TriDisModStdAddFlex[7]
              RobustAvgAddCost [8] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
            if(TSize>TMSize)
```

```
            {
              FlexMaxAddCost [8]   = (587770.49 + 255.30046*(TSize-TMSize) - 0.0342524*((
TSize-TMSize)-1100)^2)*TriDisModStdAddStd[7]
              FlexMaxAddCost [8]   = FlexMaxAddCost [8] + (102596.39 + 96.037325*(AddSize
-TSize+TMSize) - 0.0293642*((AddSize-TSize+TMSize)-1100)^2)*TriDisModStdAddFlex[7]
              RobustMaxAddCost [8] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSiz
e-1100)^2)*TriDisModStdAddStd[7]
            }else
            {
              FlexMaxAddCost [8]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize)
-1100)^2)*TriDisModStdAddFlex[7]
              RobustMaxAddCost [8] = 0
            }
          } else
          {
            AddCost [8] = (762491.78 + 294.13388*AddSize - 0.0289768*(AddSize-1100)^2)*Tr
iDisModStdAddStd[7]

            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {
              FlexAvgAddCost [8]   = (762491.78 + 294.13388*(TSize-TASize) - 0.0289768*((
TSize-TASize)-1100)^2)*TriDisModStdAddStd[7]
              FlexAvgAddCost [8]   = FlexAvgAddCost [8] + (120923.57 + 119.31587*(AddSize
-TSize+TASize) - 0.022339*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[7]
              RobustAvgAddCost [8] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSiz
e-1100)^2)*TriDisModStdAddStd[7]
            }else
            {
              FlexAvgAddCost [8]   = (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSiz
e)-1100)^2)*TriDisModStdAddFlex[7]
              RobustAvgAddCost [8] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
            if(TSize>TMSize)
            {
              FlexMaxAddCost [8]   = (762491.78 + 294.13388*(TSize-TMSize) - 0.0289768*((
TSize-TMSize)-1100)^2 )*TriDisModStdAddStd[7]
              FlexMaxAddCost [8]   = FlexMaxAddCost [8] + (120923.57 + 119.31587*(AddSize
-TSize+TMSize) - 0.022339*((AddSize-TSize+TMSize)-1100)^2 )*TriDisModStdAddFlex[7]
              RobustMaxAddCost [8] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSiz
e-1100)^2)*TriDisModStdAddStd[7]
            }else
            {
              FlexMaxAddCost [8]= (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSize)-
1100)^2)*TriDisModStdAddFlex[7]
              RobustMaxAddCost [8] = 0
```

```
          }
        }
      } else
      {
        AddCost [8] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[7]

        'Determines addition Cost for average flexible and robust designs'
        if(TSize>TASize)
        {
          FlexAvgAddCost [8]   = (841127.96 + 208.01641*(TSize-TASize) - 0.0001798*((TS
ize-TASize)-27413.8)^2 + 0.0000000010082*((TSize-TASize)-27413.8)^3)*TriDisModStdAddStd[7
]
          FlexAvgAddCost [8]   = FlexAvgAddCost [8] + (748729.11 + 267.12747*(AddSize-T
Size+TASize))*TriDisModStdAddFlex[7]
          RobustAvgAddCost [8] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[7]
        }else
        {
          FlexAvgAddCost [8]   = (748729.11 + 267.12747*AddSize)*TriDisModStdAddFlex[7]
          RobustAvgAddCost [8] = 0
        }
        'Determines addition Cost for max flexible and robust designs'
        if(TSize>TMSize)
        {
          FlexMaxAddCost [8]   = (841127.96 + 208.01641*(TSize-TMSize) - 0.0001798*((TS
ize-TMSize)-27413.8)^2 + 0.0000000010082*((TSize-TMSize)-27413.8)^3)*TriDisModStdAddStd[7
]
          FlexMaxAddCost [8]   = FlexMaxAddCost [8] + (727335.73 + 308.56524*(AddSize-T
Size+TMSize) - 0.000058747*((AddSize-TSize+TMSize)-27413.8)^2)*TriDisModStdAddFlex[7]
          RobustMaxAddCost [8] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[7]
        }else
        {
          FlexMaxAddCost [8]   = (727335.73 + 308.56524*(AddSize) - 0.000058747*((AddSi
ze)-27413.8)^2)*TriDisModStdAddFlex[7]
          RobustMaxAddCost [8] = 0
        }
      }
    } else
    {
      AddCost [8] = 0
      FlexAvgAddCost [8] = 0
      FlexMaxAddCost [8] = 0
      RobustAvgAddCost [8] = 0
      RobustMaxAddCost [8] = 0
    }
  } else
  {
    AddCost [8] = 0
```

```
      FlexAvgAddCost [8] = 0
      FlexMaxAddCost [8] = 0
      RobustAvgAddCost [8] = 0
      RobustMaxAddCost [8] = 0
    }

    '- Year 8 Predicted Costs'
    '---Annual operational costs for each facility Size'
    if(TSize<9000)
    {
      OpCost [9]     = (22075.001 + 11.576496*TSize)*TriDisOpYr08
      AvgOpCost [9]  = (22075.001 + 11.576496*TASize)*TriDisOpYr08
      MaxOpCost [9]  = (22075.001 + 11.576496*TMSize)*TriDisOpYr08
    } else
    {
      OpCost [9]     = (65505.38 + 9.8871903*TSize)*TriDisOpYr08
      AvgOpCost [9]  = (65505.38 + 9.8871903*TASize)*TriDisOpYr08
      MaxOpCost [9]  = (65505.38 + 9.8871903*TMSize)*TriDisOpYr08
    }

    '---Modifications predicted in Lifecycle and their costs'
    '----HVAC Modification'
    'Random variable used to determine what year modification occured'
    HVAC19yrRandP = runif(1, min = 0, max = 1) # P = Period of modification
    HVAC19yrRandY = runif(1, min = 0, max = 1) # Y = Year of modification
    'If statement determines if modification occurred it the set time period'
    if(HVAC19yrRandP<ModP_HVAC_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if(HVAC7yrRandY<=0.1200)
      {
        if(NbrStories == 1)
        {
          HVACCostMean [9] = (171399.41 + 17.39759*TSize)*TriDisModHVACMean[8]
          HVACCostMedian [9] = (154855.44 + 3.81795606*TSize)*TriDisModHVACMedian[8]
        }
        else
        {
          HVACCostMean [9] = (196252.41 + 17.839797*TSize)*TriDisModHVACMean[8]
          HVACCostMedian [9] = (156490.77 + 3.9482492*TSize)*TriDisModHVACMedian[8]
        }

      } else
      {
        HVACCostMean [9] = 0
        HVACCostMedian [9] = 0
```

```
      }
    } else
    {
      HVACCostMean [9] = 0
      HVACCostMedian [9] = 0
    }
    '----COMM Modification'
    'If statement determines if modification occurred it the set time period'
    if(COMM8yrRandP<ModP_COMM_8)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((COMM8yrRandY<=1) & (COMM8yrRandY>0.8800))
      {
        COMMCostMean [9] = (80771.311 + 7.2269841*TSize)*TriDisModCOMMMean[8]
        COMMCostMedian [9] = (85440.873 + 3.1165737*TSize)*TriDisModCOMMMedian[8]
      } else
      {
        COMMCostMean [9] = 0
        COMMCostMedian [9] = 0
      }
    }else
    {
      COMMCostMean [9] = 0
      COMMCostMedian [9] = 0
    }
    '----Electrical Modification'
    'If statement determines if modification occurred it the set time period'
    if(Elect19yrRandP<ModP_Elect_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Elect19yrRandY<=0.3103) & (Elect19yrRandY>0.2414))
      {
        ElectCostMean [9] = (72737.512 + 9.3469036*TSize)*TriDisModElectricMean[8]
        ElectCostMedian [9] = (76229.68 + 6.4750386*TSize)*TriDisModElectricMedian[8]
      } else
      {
        ElectCostMean [9] = 0
        ElectCostMedian [9] = 0
      }
    }else
    {
      ElectCostMean [9] = 0
      ElectCostMedian [9] = 0
    }
    '----Plumbing Modification'
```

```
    'Random variable used to determine what year modification occured'
    Plumb19yrRandP = runif(1, min = 0, max = 1.000) # P = Period of modification
    Plumb19yrRandY = runif(1, min = 0, max = 1.000) # Y = Year of modification
    'If statement determines if modification occurred it the set time period'
    if(Plumb19yrRandP<ModP_Plumb_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if(Plumb19yrRandY<=0.2000)
      {
        PlumbCostMean [9] = (80642.564 + 4.9662331*TSize)*TriDisModPlumbMean[8]
        PlumbCostMedian [9] = (86414.902 + 1.6289302*TSize)*TriDisModPlumbMedian[8]
      } else
      {
        PlumbCostMean [9] = 0
        PlumbCostMedian [9] = 0
      }
    } else
    {
      PlumbCostMean [9] = 0
      PlumbCostMedian [9] = 0
    }
    '----Facility Addition'
    'If statement determines if modification occurred it the set time period'
    if(Add19yrRandP<ModP_Add_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Add19yrRandY<=0.7037) & (Add19yrRandY>0.6296))
      {
        'Random selection of addition size based on weibull distro'
        AddSize = rweibull(1, shape = 1.3062133, scale = 1742.5275)
        'Updates the facility size for a potential facility lifecycle'
        TSize = TSize + AddSize
        'Set logic statements to the new facility size'
        '-Standard Size less than 9K but greater than 4k'
        SizeLE9K    = if(TSize<=4000)    {0} else if (TSize<=9000) {1} else {0}
        'Updates modification that change when addition occurs'
        '-Standard Size'
        ModP_HVAC_19  = exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9K+3.95959468
*Code121+1.93840929*ModP_HVAC_7)/(1+exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9
K+3.95959468*Code121+1.93840929*ModP_HVAC_7))
        ModP_COMM_19  = exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeLE9K+3.8671011
5*Code675+2.21037167*ModP_COMM_8)/(1+exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeL
E9K+3.86710115*Code675+2.21037167*ModP_COMM_8))
        'Recodes the cost of the addition based on size and number of stories'
        if(AddSize <= 2000)
```

```
        {
          if(NbrStories == 1)
          {
            AddCost [9] = (587770.49 + 255.30046*AddSize - 0.0342524*(AddSize-1100)^2)*Tr
iDisModStdAddStd[8]

            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {
              FlexAvgAddCost [9]   = (587770.49 + 255.30046*(TSize-TASize) - 0.0342524*((
TSize-TASize)-1100)^2 )*TriDisModStdAddStd[8]
              FlexAvgAddCost [9]   = FlexAvgAddCost [9] + (102596.39 + 96.037325*(AddSize
-TSize+TASize) - 0.0293642*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[8]
              RobustAvgAddCost [9] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSiz
e-1100)^2)*TriDisModStdAddStd[8]
            }else
            {
              FlexAvgAddCost [9]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize)
-1100)^2)*TriDisModStdAddFlex[8]
              RobustAvgAddCost [9] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
            if(TSize>TMSize)
            {
              FlexMaxAddCost [9]   = (587770.49 + 255.30046*(TSize-TMSize) - 0.0342524*((
TSize-TMSize)-1100)^2)*TriDisModStdAddStd[8]
              FlexMaxAddCost [9]   = FlexMaxAddCost [9] + (102596.39 + 96.037325*(AddSize
-TSize+TMSize) - 0.0293642*((AddSize-TSize+TMSize)-1100)^2)*TriDisModStdAddFlex[8]
              RobustMaxAddCost [9] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSiz
e-1100)^2)*TriDisModStdAddStd[8]
            }else
            {
              FlexMaxAddCost [9]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize)
-1100)^2)*TriDisModStdAddFlex[8]
              RobustMaxAddCost [9] = 0
            }
          } else
          {
            AddCost [9] = (762491.78 + 294.13388*AddSize - 0.0289768*(AddSize-1100)^2)*Tr
iDisModStdAddStd[8]

            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {
              FlexAvgAddCost [9]   = (762491.78 + 294.13388*(TSize-TASize) - 0.0289768*((
TSize-TASize)-1100)^2)*TriDisModStdAddStd[8]
              FlexAvgAddCost [9]   = FlexAvgAddCost [9] + (120923.57 + 119.31587*(AddSize
```

```
-TSize+TASize) - 0.022339*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[8]
              RobustAvgAddCost [9] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSiz
e-1100)^2)*TriDisModStdAddStd[8]
            }else
            {
              FlexAvgAddCost [9]   = (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSiz
e)-1100)^2)*TriDisModStdAddFlex[8]
              RobustAvgAddCost [9] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
            if(TSize>TMSize)
            {
              FlexMaxAddCost [9]   = (762491.78 + 294.13388*(TSize-TMSize) - 0.0289768*((
TSize-TMSize)-1100)^2 )*TriDisModStdAddStd[8]
              FlexMaxAddCost [9]   = FlexMaxAddCost [9] + (120923.57 + 119.31587*(AddSize
-TSize+TMSize) - 0.022339*((AddSize-TSize+TMSize)-1100)^2 )*TriDisModStdAddFlex[8]
              RobustMaxAddCost [9] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSiz
e-1100)^2)*TriDisModStdAddStd[8]
            }else
            {
              FlexMaxAddCost [9]= (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSize)-
1100)^2)*TriDisModStdAddFlex[8]
              RobustMaxAddCost [9] = 0
            }
          }
        } else
        {
          AddCost [9] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[8]

          'Determines addition Cost for average flexible and robust designs'
          if(TSize>TASize)
          {
            FlexAvgAddCost [9]   = (841127.96 + 208.01641*(TSize-TASize) - 0.0001798*((TS
ize-TASize)-27413.8)^2 + 0.0000000010082*((TSize-TASize)-27413.8)^3)*TriDisModStdAddStd[8
]
            FlexAvgAddCost [9]   = FlexAvgAddCost [9] + (748729.11 + 267.12747*(AddSize-T
Size+TASize))*TriDisModStdAddFlex[8]
            RobustAvgAddCost [9] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[8]
          }else
          {
            FlexAvgAddCost [9]   = (748729.11 + 267.12747*AddSize)*TriDisModStdAddFlex[8]
            RobustAvgAddCost [9] = 0
          }
          'Determines addition Cost for max flexible and robust designs'
          if(TSize>TMSize)
          {
            FlexMaxAddCost [9]   = (841127.96 + 208.01641*(TSize-TMSize) - 0.0001798*((TS
```

```
ize-TMSize)-27413.8)^2 + 0.0000000010082*((TSize-TMSize)-27413.8)^3)*TriDisModStdAddStd[8
]
            FlexMaxAddCost [9]   = FlexMaxAddCost [9] + (727335.73 + 308.56524*(AddSize-T
Size+TMSize) - 0.000058747*((AddSize-TSize+TMSize)-27413.8)^2)*TriDisModStdAddFlex[8]
            RobustMaxAddCost [9] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[8]
          }else
          {
            FlexMaxAddCost [9]   = (727335.73 + 308.56524*(AddSize) - 0.000058747*((AddSi
ze)-27413.8)^2)*TriDisModStdAddFlex[8]
            RobustMaxAddCost [9] = 0
          }
        }
      } else
      {
        AddCost [9] = 0
        FlexAvgAddCost [9] = 0
        FlexMaxAddCost [9] = 0
        RobustAvgAddCost [9] = 0
        RobustMaxAddCost [9] = 0
      }
    } else
    {
      AddCost [9] = 0
      FlexAvgAddCost [9] = 0
      FlexMaxAddCost [9] = 0
      RobustAvgAddCost [9] = 0
      RobustMaxAddCost [9] = 0
    }

    '- Year 9 Predicted Costs'
    '---Annual operational costs for each facility Size'
    if(TSize<9000)
    {
      OpCost [10]     = (19549.046 + 12.449475*TSize)*TriDisOpYr09
      AvgOpCost [10]  = (19549.046 + 12.449475*TASize)*TriDisOpYr09
      MaxOpCost [10]  = (19549.046 + 12.449475*TMSize)*TriDisOpYr09
    } else
    {
      OpCost [10]     = (65806.833 + 9.8889093*TSize)*TriDisOpYr09
      AvgOpCost [10]  = (65806.833 + 9.8889093*TASize)*TriDisOpYr09
      MaxOpCost [10]  = (65806.833 + 9.8889093*TMSize)*TriDisOpYr09
    }

    '---Modifications predicted in Lifecycle and their costs'
    '----HVAC Modification'
    'If statement determines if modification occurred it the set time period'
    if(HVAC19yrRandP<ModP_HVAC_19)
```

```
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((HVAC7yrRandY<=0.2400) & (HVAC7yrRandY>0.1200))
      {
        if(NbrStories == 1)
        {
          HVACCostMean [10] = (171399.41 + 17.39759*TSize)*TriDisModHVACMean[9]
          HVACCostMedian [10] = (154855.44 + 3.81795606*TSize)*TriDisModHVACMedian[9]
        }
        else
        {
          HVACCostMean [10] = (196252.41 + 17.839797*TSize)*TriDisModHVACMean[9]
          HVACCostMedian [10] = (156490.77 + 3.9482492*TSize)*TriDisModHVACMedian[9]
        }

      } else
      {
        HVACCostMean [10] = 0
        HVACCostMedian [10] = 0
      }
    } else
    {
      HVACCostMean [10] = 0
      HVACCostMedian [10] = 0
    }
    '----COMM Modification'
    'Random variable used to determine what year modification occured'
    COMM19yrRandP = runif(1, min = 0, max = 1)
    COMM19yrRandY = runif(1, min = 0, max = 1)
    'If statement determines if modification occurred it the set time period'
    if(COMM19yrRandP<ModP_COMM_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if(COMM19yrRandY<=0.0500)
      {
        COMMCostMean [10] = (80771.311 + 7.2269841*TSize)*TriDisModCOMMMean[9]
        COMMCostMedian [10] = (85440.873 + 3.1165737*TSize)*TriDisModCOMMMedian[9]
      } else
      {
        COMMCostMean [10] = 0
        COMMCostMedian [10] = 0
      }
    }else
    {
      COMMCostMean [10] = 0
```

```
      COMMCostMedian [10] = 0
    }
    '----Electrical Modification'
    'If statement determines if modification occurred it the set time period'
    if(Elect19yrRandP<ModP_Elect_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Elect19yrRandY<=0.5172) & (Elect19yrRandY>0.3103))
      {
        ElectCostMean [10] = (72737.512 + 9.3469036*TSize)*TriDisModElectricMean[9]
        ElectCostMedian [10] = (76229.68 + 6.4750386*TSize)*TriDisModElectricMedian[9]
      } else
      {
        ElectCostMean [10] = 0
        ElectCostMedian [10] = 0
      }
    }else
    {
      ElectCostMean [10] = 0
      ElectCostMedian [10] = 0
    }
    '----Plumbing Modification'
    'If statement determines if modification occurred it the set time period'
    if(Plumb19yrRandP<ModP_Plumb_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Plumb19yrRandY<=0.5500) & (Plumb19yrRandY>0.2000))
      {
        PlumbCostMean [10] = (80642.564 + 4.9662331*TSize)*TriDisModPlumbMean[9]
        PlumbCostMedian [10] = (86414.902 + 1.6289302*TSize)*TriDisModPlumbMedian[9]
      } else
      {
        PlumbCostMean [10] = 0
        PlumbCostMedian [10] = 0
      }
    } else
    {
      PlumbCostMean [10] = 0
      PlumbCostMedian [10] = 0
    }
    '----Facility Addition'
    'If statement determines if modification occurred it the set time period'
    if(Add19yrRandP<ModP_Add_19)
    {
      'If Statement determines if the modification occured in this year and records the c
```

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ost'
      if((Add19yrRandY<=0.8148) & (Add19yrRandY>0.7037))
      {
        'Random selection of addition size based on weibull distro'
        AddSize = rweibull(1, shape = 1.3062133, scale = 1742.5275)
        'Updates the facility size for a potential facility lifecycle'
        TSize = TSize + AddSize
        'Set logic statements to the new facility size'
        '-Standard Size less than 9K but greater than 4k'
        SizeLE9K    = if(TSize<=4000)    {0} else if (TSize<=9000) {1} else {0}
        'Updates modification that change when addition occurs'
        '-Standard Size'
        ModP_HVAC_19  = exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9K+3.95959468
*Code121+1.93840929*ModP_HVAC_7)/(1+exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9
K+3.95959468*Code121+1.93840929*ModP_HVAC_7))
        ModP_COMM_19  = exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeLE9K+3.8671011
5*Code675+2.21037167*ModP_COMM_8)/(1+exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeL
E9K+3.86710115*Code675+2.21037167*ModP_COMM_8))
        'Recodes the cost of the addition based on size and number of stories'
        if(AddSize <= 2000)
        {
          if(NbrStories == 1)
          {
            AddCost [10] = (587770.49 + 255.30046*AddSize - 0.0342524*(AddSize-1100)^2)*T
riDisModStdAddStd[9]
            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {
              FlexAvgAddCost [10]   = (587770.49 + 255.30046*(TSize-TASize) - 0.0342524*(
(TSize-TASize)-1100)^2 )*TriDisModStdAddStd[9]
              FlexAvgAddCost [10]   = FlexAvgAddCost [10] + (102596.39 + 96.037325*(AddSi
ze-TSize+TASize) - 0.0293642*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[9]
              RobustAvgAddCost [10] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSi
ze-1100)^2)*TriDisModStdAddStd[9]
            }else
            {
              FlexAvgAddCost [10]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize
)-1100)^2)*TriDisModStdAddFlex[9]
              RobustAvgAddCost [10] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
            if(TSize>TMSize)
            {
              FlexMaxAddCost [10]   = (587770.49 + 255.30046*(TSize-TMSize) - 0.0342524*(
(TSize-TMSize)-1100)^2)*TriDisModStdAddStd[9]
              FlexMaxAddCost [10]   = FlexMaxAddCost [10] + (102596.39 + 96.037325*(AddSi
ze-TSize+TMSize) - 0.0293642*((AddSize-TSize+TMSize)-1100)^2)*TriDisModStdAddFlex[9]
```

```
              RobustMaxAddCost [10] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSi
ze-1100)^2)*TriDisModStdAddStd[9]
            }else
            {
              FlexMaxAddCost [10]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize
)-1100)^2)*TriDisModStdAddFlex[9]
              RobustMaxAddCost [10] = 0
            }
          } else
          {
            AddCost [10] = (762491.78 + 294.13388*AddSize - 0.0289768*(AddSize-1100)^2)*T
riDisModStdAddStd[9]

            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {
              FlexAvgAddCost [10]   = (762491.78 + 294.13388*(TSize-TASize) - 0.0289768*(
(TSize-TASize)-1100)^2)*TriDisModStdAddStd[9]
              FlexAvgAddCost [10]   = FlexAvgAddCost [10] + (120923.57 + 119.31587*(AddSi
ze-TSize+TASize) - 0.022339*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[9]
              RobustAvgAddCost [10] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSi
ze-1100)^2)*TriDisModStdAddStd[9]
            }else
            {
              FlexAvgAddCost [10]   = (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSi
ze)-1100)^2)*TriDisModStdAddFlex[9]
              RobustAvgAddCost [10] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
            if(TSize>TMSize)
            {
              FlexMaxAddCost [10]   = (762491.78 + 294.13388*(TSize-TMSize) - 0.0289768*(
(TSize-TMSize)-1100)^2 )*TriDisModStdAddStd[9]
              FlexMaxAddCost [10]   = FlexMaxAddCost [10] + (120923.57 + 119.31587*(AddSi
ze-TSize+TMSize) - 0.022339*((AddSize-TSize+TMSize)-1100)^2 )*TriDisModStdAddFlex[9]
              RobustMaxAddCost [10] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSi
ze-1100)^2)*TriDisModStdAddStd[9]
            }else
            {
              FlexMaxAddCost [10]= (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSize)
-1100)^2)*TriDisModStdAddFlex[9]
              RobustMaxAddCost [10] = 0
            }
          }
        } else
        {
          AddCost [10] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[9]
```

```
          'Determines addition Cost for average flexible and robust designs'
          if(TSize>TASize)
          {
            FlexAvgAddCost [10]   = (841127.96 + 208.01641*(TSize-TASize) - 0.0001798*((T
Size-TASize)-27413.8)^2 + 0.0000000010082*((TSize-TASize)-27413.8)^3)*TriDisModStdAddStd[
9]
            FlexAvgAddCost [10]   = FlexAvgAddCost [10] + (748729.11 + 267.12747*(AddSize
-TSize+TASize))*TriDisModStdAddFlex[9]
            RobustAvgAddCost [10] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[9]
          }else
          {
            FlexAvgAddCost [10]   = (748729.11 + 267.12747*AddSize)*TriDisModStdAddFlex[9
]
            RobustAvgAddCost [10] = 0
          }
          'Determines addition Cost for max flexible and robust designs'
          if(TSize>TMSize)
          {
            FlexMaxAddCost [10]   = (841127.96 + 208.01641*(TSize-TMSize) - 0.0001798*((T
Size-TMSize)-27413.8)^2 + 0.0000000010082*((TSize-TMSize)-27413.8)^3)*TriDisModStdAddStd[
9]
            FlexMaxAddCost [10]   = FlexMaxAddCost [10] + (727335.73 + 308.56524*(AddSize
-TSize+TMSize) - 0.000058747*((AddSize-TSize+TMSize)-27413.8)^2)*TriDisModStdAddFlex[9]
            RobustMaxAddCost [10] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[9]
          }else
          {
            FlexMaxAddCost [10]   = (727335.73 + 308.56524*(AddSize) - 0.000058747*((AddS
ize)-27413.8)^2)*TriDisModStdAddFlex[9]
            RobustMaxAddCost [10] = 0
          }
        }
      } else
      {
        AddCost [10] = 0
        FlexAvgAddCost [10] = 0
        FlexMaxAddCost [10] = 0
        RobustAvgAddCost [10] = 0
        RobustMaxAddCost [10] = 0
      }
    } else
    {
      AddCost [10] = 0
      FlexAvgAddCost [10] = 0
      FlexMaxAddCost [10] = 0
      RobustAvgAddCost [10] = 0
      RobustMaxAddCost [10] = 0
```

```
    }

    '- Year 10 Predicted Costs'
    '---Annual operational costs for each facility Size'
    if(TSize<9000)
    {
      OpCost [11]     = (20439.941 + 12.226986*TSize)*TriDisOpYr10
      AvgOpCost [11]  = (20439.941 + 12.226986*TASize)*TriDisOpYr10
      MaxOpCost [11]  = (20439.941 + 12.226986*TMSize)*TriDisOpYr10
    } else
    {
      OpCost [11]     = (59977.379 + 9.989776*TSize)*TriDisOpYr10
      AvgOpCost [11]  = (59977.379 + 9.989776*TASize)*TriDisOpYr10
      MaxOpCost [11]  = (59977.379 + 9.989776*TMSize)*TriDisOpYr10
    }

    '---Modifications predicted in Lifecycle and their costs'
    '----HVAC Modification'
    'If statement determines if modification occurred it the set time period'
    if(HVAC19yrRandP<ModP_HVAC_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((HVAC7yrRandY<=0.4400) & (HVAC7yrRandY>0.2400))
      {
        if(NbrStories == 1)
        {
          HVACCostMean [11] = (171399.41 + 17.39759*TSize)*TriDisModHVACMean[10]
          HVACCostMedian [11] = (154855.44 + 3.81795606*TSize)*TriDisModHVACMedian[10]
        }
        else
        {
          HVACCostMean [11] = (196252.41 + 17.839797*TSize)*TriDisModHVACMean[10]
          HVACCostMedian [11] = (156490.77 + 3.9482492*TSize)*TriDisModHVACMedian[10]
        }

      } else
      {
        HVACCostMean [11] = 0
        HVACCostMedian [11] = 0
      }
    } else
    {
      HVACCostMean [11] = 0
      HVACCostMedian [11] = 0
    }
    '----COMM Modification'
```

```
    'If statement determines if modification occurred it the set time period'
    if(COMM19yrRandP<ModP_COMM_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((COMM19yrRandY<=0.3000) & (COMM19yrRandY>0.0500))
      {
        COMMCostMean [11] = (80771.311 + 7.2269841*TSize)*TriDisModCOMMMean[10]
        COMMCostMedian [11] = (85440.873 + 3.1165737*TSize)*TriDisModCOMMMedian[10]
      } else
      {
        COMMCostMean [11] = 0
        COMMCostMedian [11] = 0
      }
    }else
    {
      COMMCostMean [11] = 0
      COMMCostMedian [11] = 0
    }
    '----Electrical Modification'
    'If statement determines if modification occurred it the set time period'
    if(Elect19yrRandP<ModP_Elect_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Elect19yrRandY<=0.72) & (Elect19yrRandY>0.5172))
      {
        ElectCostMean [11] = (72737.512 + 9.3469036*TSize)*TriDisModElectricMean[10]
        ElectCostMedian [11] = (76229.68 + 6.4750386*TSize)*TriDisModElectricMedian[10]
      } else
      {
        ElectCostMean [11] = 0
        ElectCostMedian [11] = 0
      }
    }else
    {
      ElectCostMean [11] = 0
      ElectCostMedian [11] = 0
    }
    '----Plumbing Modification'
    'If statement determines if modification occurred it the set time period'
    if(Plumb19yrRandP<ModP_Plumb_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Plumb19yrRandY<=0.7000) & (Plumb19yrRandY>0.5500))
      {
```

```
        PlumbCostMean [11] = (80642.564 + 4.9662331*TSize)*TriDisModPlumbMean[10]
        PlumbCostMedian [11] = (86414.902 + 1.6289302*TSize)*TriDisModPlumbMedian[10]
      } else
      {
        PlumbCostMean [11] = 0
        PlumbCostMedian [11] = 0
      }
    } else
    {
      PlumbCostMean [11] = 0
      PlumbCostMedian [11] = 0
    }
    '----Facility Addition'
    'If statement determines if modification occurred it the set time period'
    if(Add19yrRandP<ModP_Add_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Add19yrRandY<=0.8148) & (Add19yrRandY>0.8148))
      {
        'Random selection of addition size based on weibull distro'
        AddSize = rweibull(1, shape = 1.3062133, scale = 1742.5275)
        'Updates the facility size for a potential facility lifecycle'
        TSize = TSize + AddSize
        'Set logic statements to the new facility size'
        '-Standard Size less than 9K but greater than 4k'
        SizeLE9K    = if(TSize<=4000)    {0} else if (TSize<=9000) {1} else {0}
        'Updates modification that change when addition occurs'
        '-Standard Size'
        ModP_HVAC_19  = exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9K+3.95959468
*Code121+1.93840929*ModP_HVAC_7)/(1+exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9
K+3.95959468*Code121+1.93840929*ModP_HVAC_7))
        ModP_COMM_19  = exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeLE9K+3.8671011
5*Code675+2.21037167*ModP_COMM_8)/(1+exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeL
E9K+3.86710115*Code675+2.21037167*ModP_COMM_8))
        'Recodes the cost of the addition based on size and number of stories'
        if(AddSize <= 2000)
        {
          if(NbrStories == 1)
          {
            AddCost [11] = (587770.49 + 255.30046*AddSize - 0.0342524*(AddSize-1100)^2)*T
riDisModStdAddStd[10]

            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {
              FlexAvgAddCost [11]   = (587770.49 + 255.30046*(TSize-TASize) - 0.0342524*(
```

```
(TSize-TASize)-1100)^2 )*TriDisModStdAddStd[10]
              FlexAvgAddCost [11]   = FlexAvgAddCost [11] + (102596.39 + 96.037325*(AddSi
ze-TSize+TASize) - 0.0293642*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[10]
              RobustAvgAddCost [11] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSi
ze-1100)^2)*TriDisModStdAddStd[10]
            }else
            {
              FlexAvgAddCost [11]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize
)-1100)^2)*TriDisModStdAddFlex[10]
              RobustAvgAddCost [11] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
            if(TSize>TMSize)
            {
              FlexMaxAddCost [11]   = (587770.49 + 255.30046*(TSize-TMSize) - 0.0342524*(
(TSize-TMSize)-1100)^2)*TriDisModStdAddStd[10]
              FlexMaxAddCost [11]   = FlexMaxAddCost [11] + (102596.39 + 96.037325*(AddSi
ze-TSize+TMSize) - 0.0293642*((AddSize-TSize+TMSize)-1100)^2)*TriDisModStdAddFlex[10]
              RobustMaxAddCost [11] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSi
ze-1100)^2)*TriDisModStdAddStd[10]
            }else
            {
              FlexMaxAddCost [11]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize
)-1100)^2)*TriDisModStdAddFlex[10]
              RobustMaxAddCost [11] = 0
            }
          } else
          {
            AddCost [11] = (762491.78 + 294.13388*AddSize - 0.0289768*(AddSize-1100)^2)*T
riDisModStdAddStd[10]

            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {
              FlexAvgAddCost [11]   = (762491.78 + 294.13388*(TSize-TASize) - 0.0289768*(
(TSize-TASize)-1100)^2)*TriDisModStdAddStd[10]
              FlexAvgAddCost [11]   = FlexAvgAddCost [11] + (120923.57 + 119.31587*(AddSi
ze-TSize+TASize) - 0.022339*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[10]
              RobustAvgAddCost [11] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSi
ze-1100)^2)*TriDisModStdAddStd[10]
            }else
            {
              FlexAvgAddCost [11]   = (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSi
ze)-1100)^2)*TriDisModStdAddFlex[10]
              RobustAvgAddCost [11] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
```

```
            if(TSize>TMSize)
            {
              FlexMaxAddCost [11]   = (762491.78 + 294.13388*(TSize-TMSize) - 0.0289768*(
(TSize-TMSize)-1100)^2 )*TriDisModStdAddStd[10]
              FlexMaxAddCost [11]   = FlexMaxAddCost [11] + (120923.57 + 119.31587*(AddSi
ze-TSize+TMSize) - 0.022339*((AddSize-TSize+TMSize)-1100)^2 )*TriDisModStdAddFlex[10]
              RobustMaxAddCost [11] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSi
ze-1100)^2)*TriDisModStdAddStd[10]
            }else
            {
              FlexMaxAddCost [11]= (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSize)
-1100)^2)*TriDisModStdAddFlex[10]
              RobustMaxAddCost [11] = 0
            }
          }
        } else
        {
          AddCost [11] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[10]

          'Determines addition Cost for average flexible and robust designs'
          if(TSize>TASize)
          {
            FlexAvgAddCost [11]   = (841127.96 + 208.01641*(TSize-TASize) - 0.0001798*((T
Size-TASize)-27413.8)^2 + 0.0000000010082*((TSize-TASize)-27413.8)^3)*TriDisModStdAddStd[
10]
            FlexAvgAddCost [11]   = FlexAvgAddCost [11] + (748729.11 + 267.12747*(AddSize
-TSize+TASize))*TriDisModStdAddFlex[10]
            RobustAvgAddCost [11] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[10]
          }else
          {
            FlexAvgAddCost [11]   = (748729.11 + 267.12747*AddSize)*TriDisModStdAddFlex[1
0]
            RobustAvgAddCost [11] = 0
          }
          'Determines addition Cost for max flexible and robust designs'
          if(TSize>TMSize)
          {
            FlexMaxAddCost [11]   = (841127.96 + 208.01641*(TSize-TMSize) - 0.0001798*((T
Size-TMSize)-27413.8)^2 + 0.0000000010082*((TSize-TMSize)-27413.8)^3)*TriDisModStdAddStd[
10]
            FlexMaxAddCost [11]   = FlexMaxAddCost [11] + (727335.73 + 308.56524*(AddSize
-TSize+TMSize) - 0.000058747*((AddSize-TSize+TMSize)-27413.8)^2)*TriDisModStdAddFlex[10]
            RobustMaxAddCost [11] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[10]
          }else
          {
            FlexMaxAddCost [11]   = (727335.73 + 308.56524*(AddSize) - 0.000058747*((AddS
ize)-27413.8)^2)*TriDisModStdAddFlex[10]
```

```
            RobustMaxAddCost [11] = 0
          }
        }
      } else
      {
        AddCost [11] = 0
        FlexAvgAddCost [11] = 0
        FlexMaxAddCost [11] = 0
        RobustAvgAddCost [11] = 0
        RobustMaxAddCost [11] = 0
      }
    } else
    {
      AddCost [11] = 0
      FlexAvgAddCost [11] = 0
      FlexMaxAddCost [11] = 0
      RobustAvgAddCost [11] = 0
      RobustMaxAddCost [11] = 0
    }

    '- Year 11 Predicted Costs'
    '---Annual operational costs for each facility Size'
    if(TSize<9000)
    {
      OpCost [12]     = (20341.082 + 12.288582*TSize)*TriDisOpYr11
      AvgOpCost [12]  = (20341.082 + 12.288582*TASize)*TriDisOpYr11
      MaxOpCost [12]  = (20341.082 + 12.288582*TMSize)*TriDisOpYr11
    } else
    {
      OpCost [12]     = (63871.874+9.9117884*TSize)*TriDisOpYr11
      AvgOpCost [12]  = (63871.874+9.9117884*TASize)*TriDisOpYr11
      MaxOpCost [12]  = (63871.874+9.9117884*TMSize)*TriDisOpYr11
    }
    '---Modifications predicted in Lifecycle and their costs'
    '----HVAC Modification'
    'If statement determines if modification occurred it the set time period'
    if(HVAC19yrRandP<ModP_HVAC_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((HVAC7yrRandY<=0.52) & (HVAC7yrRandY>0.4400))
      {
        if(NbrStories == 1)
        {
          HVACCostMean [12] = (171399.41 + 17.39759*TSize)*TriDisModHVACMean[11]
          HVACCostMedian [12] = (154855.44 + 3.81795606*TSize)*TriDisModHVACMedian[11]
        }
```

```
        else
        {
          HVACCostMean [12] = (196252.41 + 17.839797*TSize)*TriDisModHVACMean[11]
          HVACCostMedian [12] = (156490.77 + 3.9482492*TSize)*TriDisModHVACMedian[11]
        }

      } else
      {
        HVACCostMean [12] = 0
        HVACCostMedian [12] = 0
      }
    } else
    {
      HVACCostMean [12] = 0
      HVACCostMedian [12] = 0
    }
    '----COMM Modification'
    'If statement determines if modification occurred it the set time period'
    if(COMM19yrRandP<ModP_COMM_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((COMM19yrRandY<=0.4500) & (COMM19yrRandY>0.3000))
      {
        COMMCostMean [12] = (80771.311 + 7.2269841*TSize)*TriDisModCOMMMean[11]
        COMMCostMedian [12] = (85440.873 + 3.1165737*TSize)*TriDisModCOMMMedian[11]
      } else
      {
        COMMCostMean [12] = 0
        COMMCostMedian [12] = 0
      }
    }else
    {
      COMMCostMean [12] = 0
      COMMCostMedian [12] = 0
    }
    '----Electrical Modification'
    'If statement determines if modification occurred it the set time period'
    if(Elect19yrRandP<ModP_Elect_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Elect19yrRandY<=0.6207) & (Elect19yrRandY>0.6207))
      {
        ElectCostMean [12] = (72737.512 + 9.3469036*TSize)*TriDisModElectricMean[11]
        ElectCostMedian [12] = (76229.68 + 6.4750386*TSize)*TriDisModElectricMedian[11]
      } else
```

```
      {
        ElectCostMean [12] = 0
        ElectCostMedian [12] = 0
      }
    }else
    {
      ElectCostMean [12] = 0
      ElectCostMedian [12] = 0
    }
    '----Plumbing Modification'
    'If statement determines if modification occurred it the set time period'
    if(Plumb19yrRandP<ModP_Plumb_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Plumb19yrRandY<=0.7000) & (Plumb19yrRandY>0.7000))
      {
        PlumbCostMean [12] = (80642.564 + 4.9662331*TSize)*TriDisModPlumbMean[11]
        PlumbCostMedian [12] = (86414.902 + 1.6289302*TSize)*TriDisModPlumbMedian[11]
      } else
      {
        PlumbCostMean [12] = 0
        PlumbCostMedian [12] = 0
      }
    } else
    {
      PlumbCostMean [12] = 0
      PlumbCostMedian [12] = 0
    }
    '----Facility Addition'
    'If statement determines if modification occurred it the set time period'
    if(Add19yrRandP<ModP_Add_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Add19yrRandY<=0.8519) & (Add19yrRandY>0.8148))
      {
        'Random selection of addition size based on weibull distro'
        AddSize = rweibull(1, shape = 1.3062133, scale = 1742.5275)
        'Updates the facility size for a potential facility lifecycle'
        TSize = TSize + AddSize
        'Set logic statements to the new facility size'
        '-Standard Size less than 9K but greater than 4k'
        SizeLE9K    = if(TSize<=4000)    {0} else if (TSize<=9000) {1} else {0}
        'Updates modification that change when addition occurs'
        '-Standard Size'
        ModP_HVAC_19  = exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9K+3.95959468
```

```
*Code121+1.93840929*ModP_HVAC_7)/(1+exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9
K+3.95959468*Code121+1.93840929*ModP_HVAC_7))
        ModP_COMM_19  = exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeLE9K+3.8671011
5*Code675+2.21037167*ModP_COMM_8)/(1+exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeL
E9K+3.86710115*Code675+2.21037167*ModP_COMM_8))
        'Recodes the cost of the addition based on size and number of stories'
        if(AddSize <= 2000)
        {
          if(NbrStories == 1)
          {
            AddCost [12] = (587770.49 + 255.30046*AddSize - 0.0342524*(AddSize-1100)^2)*T
riDisModStdAddStd[11]

            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {
              FlexAvgAddCost [12]   = (587770.49 + 255.30046*(TSize-TASize) - 0.0342524*(
(TSize-TASize)-1100)^2 )*TriDisModStdAddStd[11]
              FlexAvgAddCost [12]   = FlexAvgAddCost [12] + (102596.39 + 96.037325*(AddSi
ze-TSize+TASize) - 0.0293642*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[11]
              RobustAvgAddCost [12] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSi
ze-1100)^2)*TriDisModStdAddStd[11]
            }else
            {
              FlexAvgAddCost [12]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize
)-1100)^2)*TriDisModStdAddFlex[11]
              RobustAvgAddCost [12] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
            if(TSize>TMSize)
            {
              FlexMaxAddCost [12]   = (587770.49 + 255.30046*(TSize-TMSize) - 0.0342524*(
(TSize-TMSize)-1100)^2)*TriDisModStdAddStd[11]
              FlexMaxAddCost [12]   = FlexMaxAddCost [12] + (102596.39 + 96.037325*(AddSi
ze-TSize+TMSize) - 0.0293642*((AddSize-TSize+TMSize)-1100)^2)*TriDisModStdAddFlex[11]
              RobustMaxAddCost [12] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSi
ze-1100)^2)*TriDisModStdAddStd[11]
            }else
            {
              FlexMaxAddCost [12]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize
)-1100)^2)*TriDisModStdAddFlex[11]
              RobustMaxAddCost [12] = 0
            }
          } else
          {
            AddCost [12] = (762491.78 + 294.13388*AddSize - 0.0289768*(AddSize-1100)^2)*T
riDisModStdAddStd[11]
```

```
            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {
              FlexAvgAddCost [12]   = (762491.78 + 294.13388*(TSize-TASize) - 0.0289768*(
(TSize-TASize)-1100)^2)*TriDisModStdAddStd[11]
              FlexAvgAddCost [12]   = FlexAvgAddCost [12] + (120923.57 + 119.31587*(AddSi
ze-TSize+TASize) - 0.022339*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[11]
              RobustAvgAddCost [12] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSi
ze-1100)^2)*TriDisModStdAddStd[11]
            }else
            {
              FlexAvgAddCost [12]   = (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSi
ze)-1100)^2)*TriDisModStdAddFlex[11]
              RobustAvgAddCost [12] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
            if(TSize>TMSize)
            {
              FlexMaxAddCost [12]   = (762491.78 + 294.13388*(TSize-TMSize) - 0.0289768*(
(TSize-TMSize)-1100)^2 )*TriDisModStdAddStd[11]
              FlexMaxAddCost [12]   = FlexMaxAddCost [12] + (120923.57 + 119.31587*(AddSi
ze-TSize+TMSize) - 0.022339*((AddSize-TSize+TMSize)-1100)^2 )*TriDisModStdAddFlex[11]
              RobustMaxAddCost [12] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSi
ze-1100)^2)*TriDisModStdAddStd[11]
            }else
            {
              FlexMaxAddCost [12]= (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSize)
-1100)^2)*TriDisModStdAddFlex[11]
              RobustMaxAddCost [12] = 0
            }
          }
        } else
        {
          AddCost [12] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[11]

          'Determines addition Cost for average flexible and robust designs'
          if(TSize>TASize)
          {
            FlexAvgAddCost [12]   = (841127.96 + 208.01641*(TSize-TASize) - 0.0001798*((T
Size-TASize)-27413.8)^2 + 0.0000000010082*((TSize-TASize)-27413.8)^3)*TriDisModStdAddStd[
11]
            FlexAvgAddCost [12]   = FlexAvgAddCost [12] + (748729.11 + 267.12747*(AddSize
-TSize+TASize))*TriDisModStdAddFlex[11]
            RobustAvgAddCost [12] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[11]
          }else
          {
```

```
            FlexAvgAddCost [12]   = (748729.11 + 267.12747*AddSize)*TriDisModStdAddFlex[1
1]
            RobustAvgAddCost [12] = 0
          }
          'Determines addition Cost for max flexible and robust designs'
          if(TSize>TMSize)
          {
            FlexMaxAddCost [12]   = (841127.96 + 208.01641*(TSize-TMSize) - 0.0001798*((T
Size-TMSize)-27413.8)^2 + 0.0000000010082*((TSize-TMSize)-27413.8)^3)*TriDisModStdAddStd[
11]
            FlexMaxAddCost [12]   = FlexMaxAddCost [12] + (727335.73 + 308.56524*(AddSize
-TSize+TMSize) - 0.000058747*((AddSize-TSize+TMSize)-27413.8)^2)*TriDisModStdAddFlex[11]
            RobustMaxAddCost [12] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[11]
          }else
          {
            FlexMaxAddCost [12]   = (727335.73 + 308.56524*(AddSize) - 0.000058747*((AddS
ize)-27413.8)^2)*TriDisModStdAddFlex[11]
            RobustMaxAddCost [12] = 0
          }
        }
      } else
      {
        AddCost [12] = 0
        FlexAvgAddCost [12] = 0
        FlexMaxAddCost [12] = 0
        RobustAvgAddCost [12] = 0
        RobustMaxAddCost [12] = 0
      }
    } else
    {
      AddCost [12] = 0
      FlexAvgAddCost [12] = 0
      FlexMaxAddCost [12] = 0
      RobustAvgAddCost [12] = 0
      RobustMaxAddCost [12] = 0
    }

    '-Year 12 Predicted Costs'
    '---Annual operational costs for each facility Size'
    if(TSize<9000)
    {
      OpCost [13]     = (19274.219+12.890909*TSize)*TriDisOpYr12
      AvgOpCost [13]  = (19274.219+12.890909*TASize)*TriDisOpYr12
      MaxOpCost [13]  = (19274.219+12.890909*TMSize)*TriDisOpYr12
    } else
    {
      OpCost [13]     = (67661.237 + 9.8951649*TSize)*TriDisOpYr12
```

```
      AvgOpCost [13]  = (67661.237 + 9.8951649*TASize)*TriDisOpYr12
      MaxOpCost [13]  = (67661.237 + 9.8951649*TMSize)*TriDisOpYr12
    }

    '---Modifications predicted in Lifecycle and their costs'
    '----HVAC Modification'
    'If statement determines if modification occurred it the set time period'
    if(HVAC19yrRandP<ModP_HVAC_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((HVAC7yrRandY<=0.6800) & (HVAC7yrRandY>0.52))
      {
        if(NbrStories == 1)
        {
          HVACCostMean [13] = (171399.41 + 17.39759*TSize)*TriDisModHVACMean[12]
          HVACCostMedian [13] = (154855.44 + 3.81795606*TSize)*TriDisModHVACMedian[12]
        }
        else
        {
          HVACCostMean [13] = (196252.41 + 17.839797*TSize)*TriDisModHVACMean[12]
          HVACCostMedian [13] = (156490.77 + 3.9482492*TSize)*TriDisModHVACMedian[12]
        }

      } else
      {
        HVACCostMean [13] = 0
        HVACCostMedian [13] = 0
      }
    } else
    {
      HVACCostMean [13] = 0
      HVACCostMedian [13] = 0
    }
    '----COMM Modification'
    'If statement determines if modification occurred it the set time period'
    if(COMM19yrRandP<ModP_COMM_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((COMM19yrRandY<=0.6500) & (COMM19yrRandY>0.4500))
      {
        COMMCostMean [13] = (80771.311 + 7.2269841*TSize)*TriDisModCOMMMean[12]
        COMMCostMedian [13] = (85440.873 + 3.1165737*TSize)*TriDisModCOMMMedian[12]
      } else
      {
        COMMCostMean [13] = 0
```

```
        COMMCostMedian [13] = 0
      }
    }else
    {
      COMMCostMean [13] = 0
      COMMCostMedian [13] = 0
    }
    '----Electrical Modification'
    'If statement determines if modification occurred it the set time period'
    if(Elect19yrRandP<ModP_Elect_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Elect19yrRandY<=00.7241) & (Elect19yrRandY>0.6207))
      {
        ElectCostMean [13] = (72737.512 + 9.3469036*TSize)*TriDisModElectricMean[12]
        ElectCostMedian [13] = (76229.68 + 6.4750386*TSize)*TriDisModElectricMedian[12]
      } else
      {
        ElectCostMean [13] = 0
        ElectCostMedian [13] = 0
      }
    }else
    {
      ElectCostMean [13] = 0
      ElectCostMedian [13] = 0
    }
    '----Plumbing Modification'
    'If statement determines if modification occurred it the set time period'
    if(Plumb19yrRandP<ModP_Plumb_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Plumb19yrRandY<=0.8000) & (Plumb19yrRandY>0.7000))
      {
        PlumbCostMean [13] = (80642.564 + 4.9662331*TSize)*TriDisModPlumbMean[12]
        PlumbCostMedian [13] = (86414.902 + 1.6289302*TSize)*TriDisModPlumbMedian[12]
      } else
      {
        PlumbCostMean [13] = 0
        PlumbCostMedian [13] = 0
      }
    } else
    {
      PlumbCostMean [13] = 0
      PlumbCostMedian [13] = 0
    }
```

```
    '----Facility Addition'
    'If statement determines if modification occurred it the set time period'
    if(Add19yrRandP<ModP_Add_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Add19yrRandY<=0.8519) & (Add19yrRandY>0.8519))
      {
        'Random selection of addition size based on weibull distro'
        AddSize = rweibull(1, shape = 1.3062133, scale = 1742.5275)
        'Updates the facility size for a potential facility lifecycle'
        TSize = TSize + AddSize
        'Set logic statements to the new facility size'
        '-Standard Size less than 9K but greater than 4k'
        SizeLE9K    = if(TSize<=4000)    {0} else if (TSize<=9000) {1} else {0}
        'Updates modification that change when addition occurs'
        '-Standard Size'
        ModP_HVAC_19  = exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9K+3.95959468
*Code121+1.93840929*ModP_HVAC_7)/(1+exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9
K+3.95959468*Code121+1.93840929*ModP_HVAC_7))
        ModP_COMM_19  = exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeLE9K+3.8671011
5*Code675+2.21037167*ModP_COMM_8)/(1+exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeL
E9K+3.86710115*Code675+2.21037167*ModP_COMM_8))
        'Recodes the cost of the addition based on size and number of stories'
        if(AddSize <= 2000)
        {
          if(NbrStories == 1)
          {
            AddCost [13] = (587770.49 + 255.30046*AddSize - 0.0342524*(AddSize-1100)^2)*T
riDisModStdAddStd[12]

            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {
              FlexAvgAddCost [13]   = (587770.49 + 255.30046*(TSize-TASize) - 0.0342524*(
(TSize-TASize)-1100)^2 )*TriDisModStdAddStd[12]
              FlexAvgAddCost [13]   = FlexAvgAddCost [13] + (102596.39 + 96.037325*(AddSi
ze-TSize+TASize) - 0.0293642*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[12]
              RobustAvgAddCost [13] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSi
ze-1100)^2)*TriDisModStdAddStd[12]
            }else
            {
              FlexAvgAddCost [13]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize
)-1100)^2)*TriDisModStdAddFlex[12]
              RobustAvgAddCost [13] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
```

```
            if(TSize>TMSize)
            {
              FlexMaxAddCost [13]   = (587770.49 + 255.30046*(TSize-TMSize) - 0.0342524*(
(TSize-TMSize)-1100)^2)*TriDisModStdAddStd[12]
              FlexMaxAddCost [13]   = FlexMaxAddCost [13] + (102596.39 + 96.037325*(AddSi
ze-TSize+TMSize) - 0.0293642*((AddSize-TSize+TMSize)-1100)^2)*TriDisModStdAddFlex[12]
              RobustMaxAddCost [13] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSi
ze-1100)^2)*TriDisModStdAddStd[12]
            }else
            {
              FlexMaxAddCost [13]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize
)-1100)^2)*TriDisModStdAddFlex[12]
              RobustMaxAddCost [13] = 0
            }
          } else
          {
            AddCost [13] = (762491.78 + 294.13388*AddSize - 0.0289768*(AddSize-1100)^2)*T
riDisModStdAddStd[12]

            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {
              FlexAvgAddCost [13]   = (762491.78 + 294.13388*(TSize-TASize) - 0.0289768*(
(TSize-TASize)-1100)^2)*TriDisModStdAddStd[12]
              FlexAvgAddCost [13]   = FlexAvgAddCost [13] + (120923.57 + 119.31587*(AddSi
ze-TSize+TASize) - 0.022339*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[12]
              RobustAvgAddCost [13] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSi
ze-1100)^2)*TriDisModStdAddStd[12]
            }else
            {
              FlexAvgAddCost [13]   = (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSi
ze)-1100)^2)*TriDisModStdAddFlex[12]
              RobustAvgAddCost [13] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
            if(TSize>TMSize)
            {
              FlexMaxAddCost [13]   = (762491.78 + 294.13388*(TSize-TMSize) - 0.0289768*(
(TSize-TMSize)-1100)^2 )*TriDisModStdAddStd[12]
              FlexMaxAddCost [13]   = FlexMaxAddCost [13] + (120923.57 + 119.31587*(AddSi
ze-TSize+TMSize) - 0.022339*((AddSize-TSize+TMSize)-1100)^2 )*TriDisModStdAddFlex[12]
              RobustMaxAddCost [13] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSi
ze-1100)^2)*TriDisModStdAddStd[12]
            }else
            {
              FlexMaxAddCost [13]= (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSize)
-1100)^2)*TriDisModStdAddFlex[12]
```

```
              RobustMaxAddCost [13] = 0
            }
          }
        } else
        {
          AddCost [13] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[12]

          'Determines addition Cost for average flexible and robust designs'
          if(TSize>TASize)
          {
            FlexAvgAddCost [13]   = (841127.96 + 208.01641*(TSize-TASize) - 0.0001798*((T
Size-TASize)-27413.8)^2 + 0.0000000010082*((TSize-TASize)-27413.8)^3)*TriDisModStdAddStd[
12]
            FlexAvgAddCost [13]   = FlexAvgAddCost [13] + (748729.11 + 267.12747*(AddSize
-TSize+TASize))*TriDisModStdAddFlex[12]
            RobustAvgAddCost [13] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[12]
          }else
          {
            FlexAvgAddCost [13]   = (748729.11 + 267.12747*AddSize)*TriDisModStdAddFlex[1
2]
            RobustAvgAddCost [13] = 0
          }
          'Determines addition Cost for max flexible and robust designs'
          if(TSize>TMSize)
          {
            FlexMaxAddCost [13]   = (841127.96 + 208.01641*(TSize-TMSize) - 0.0001798*((T
Size-TMSize)-27413.8)^2 + 0.0000000010082*((TSize-TMSize)-27413.8)^3)*TriDisModStdAddStd[
12]
            FlexMaxAddCost [13]   = FlexMaxAddCost [13] + (727335.73 + 308.56524*(AddSize
-TSize+TMSize) - 0.000058747*((AddSize-TSize+TMSize)-27413.8)^2)*TriDisModStdAddFlex[12]
            RobustMaxAddCost [13] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[12]
          }else
          {
            FlexMaxAddCost [13]   = (727335.73 + 308.56524*(AddSize) - 0.000058747*((AddS
ize)-27413.8)^2)*TriDisModStdAddFlex[12]
            RobustMaxAddCost [13] = 0
          }
        }
      } else
      {
        AddCost [13] = 0
        FlexAvgAddCost [13] = 0
        FlexMaxAddCost [13] = 0
        RobustAvgAddCost [13] = 0
        RobustMaxAddCost [13] = 0
      }
    } else
```

```
    {
      AddCost [13] = 0
      FlexAvgAddCost [13] = 0
      FlexMaxAddCost [13] = 0
      RobustAvgAddCost [13] = 0
      RobustMaxAddCost [13] = 0
    }

    '- Year 13 Predicted Costs'
    if(TSize<9000)
    {
      OpCost [14]     = (17277.527+13.589462*TSize)*TriDisOpYr13
      AvgOpCost [14]  = (17277.527+13.589462*TASize)*TriDisOpYr13
      MaxOpCost [14]  = (17277.527+13.589462*TMSize)*TriDisOpYr13
    } else
    {
      OpCost [14]     = (66890.589 + 9.9815577*TSize)*TriDisOpYr13
      AvgOpCost [14]  = (66890.589 + 9.9815577*TASize)*TriDisOpYr13
      MaxOpCost [14]  = (66890.589 + 9.9815577*TMSize)*TriDisOpYr13
    }

    '---Modifications predicted in Lifecycle and their costs'
    '----HVAC Modification'
    'If statement determines if modification occurred it the set time period'
    if(HVAC19yrRandP<ModP_HVAC_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((HVAC7yrRandY<=0.8000) & (HVAC7yrRandY>0.6800))
      {
        if(NbrStories == 1)
        {
          HVACCostMean [14] = (171399.41 + 17.39759*TSize)*TriDisModHVACMean[13]
          HVACCostMedian [14] = (154855.44 + 3.81795606*TSize)*TriDisModHVACMedian[13]
        }
        else
        {
          HVACCostMean [14] = (196252.41 + 17.839797*TSize)*TriDisModHVACMean[13]
          HVACCostMedian [14] = (156490.77 + 3.9482492*TSize)*TriDisModHVACMedian[13]
        }

      } else
      {
        HVACCostMean [14] = 0
        HVACCostMedian [14] = 0
      }
    } else
```

```
    {
      HVACCostMean [14] = 0
      HVACCostMedian [14] = 0
    }
    '----COMM Modification'
    'If statement determines if modification occurred it the set time period'
    if(COMM19yrRandP<ModP_COMM_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((COMM19yrRandY<=0.8500) & (COMM19yrRandY>0.6500))
      {
        COMMCostMean [14] = (80771.311 + 7.2269841*TSize)*TriDisModCOMMMean[13]
        COMMCostMedian [14] = (85440.873 + 3.1165737*TSize)*TriDisModCOMMMedian[13]
      } else
      {
        COMMCostMean [14] = 0
        COMMCostMedian [14] = 0
      }
    }else
    {
      COMMCostMean [14] = 0
      COMMCostMedian [14] = 0
    }
    '----Electrical Modification'
    'If statement determines if modification occurred it the set time period'
    if(Elect19yrRandP<ModP_Elect_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Elect19yrRandY<=0.8276) & (Elect19yrRandY>0.7241))
      {
        ElectCostMean [14] = (72737.512 + 9.3469036*TSize)*TriDisModElectricMean[13]
        ElectCostMedian [14] = (76229.68 + 6.4750386*TSize)*TriDisModElectricMedian[13]
      } else
      {
        ElectCostMean [14] = 0
        ElectCostMedian [14] = 0
      }
    }else
    {
      ElectCostMean [14] = 0
      ElectCostMedian [14] = 0
    }
    '----Plumbing Modification'
    'If statement determines if modification occurred it the set time period'
    if(Plumb19yrRandP<ModP_Plumb_19)
```

```
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Plumb19yrRandY<=0.8500) & (Plumb19yrRandY>0.8000))
      {
        PlumbCostMean [14] = (80642.564 + 4.9662331*TSize)*TriDisModPlumbMean[13]
        PlumbCostMedian [14] = (86414.902 + 1.6289302*TSize)*TriDisModPlumbMedian[13]
      } else
      {
        PlumbCostMean [14] = 0
        PlumbCostMedian [14] = 0
      }
    } else
    {
      PlumbCostMean [14] = 0
      PlumbCostMedian [14] = 0
    }
    '----Facility Addition'
    'If statement determines if modification occurred it the set time period'
    if(Add19yrRandP<ModP_Add_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Add19yrRandY<=0.8889) & (Add19yrRandY>0.8519))
      {
        'Random selection of addition size based on weibull distro'
        AddSize = rweibull(1, shape = 1.3062133, scale = 1742.5275)
        'Updates the facility size for a potential facility lifecycle'
        TSize = TSize + AddSize
        'Set logic statements to the new facility size'
        '-Standard Size less than 9K but greater than 4k'
        SizeLE9K    = if(TSize<=4000)    {0} else if (TSize<=9000) {1} else {0}
        'Updates modification that change when addition occurs'
        '-Standard Size'
        ModP_HVAC_19  = exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9K+3.95959468
*Code121+1.93840929*ModP_HVAC_7)/(1+exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9
K+3.95959468*Code121+1.93840929*ModP_HVAC_7))
        ModP_COMM_19  = exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeLE9K+3.8671011
5*Code675+2.21037167*ModP_COMM_8)/(1+exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeL
E9K+3.86710115*Code675+2.21037167*ModP_COMM_8))
        'Recodes the cost of the addition based on size and number of stories'
        if(AddSize <= 2000)
        {
          if(NbrStories == 1)
          {
            AddCost [14] = (587770.49 + 255.30046*AddSize - 0.0342524*(AddSize-1100)^2)*T
riDisModStdAddStd[13]
```

```
            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {
              FlexAvgAddCost [14]   = (587770.49 + 255.30046*(TSize-TASize) - 0.0342524*(
(TSize-TASize)-1100)^2 )*TriDisModStdAddStd[13]
              FlexAvgAddCost [14]   = FlexAvgAddCost [14] + (102596.39 + 96.037325*(AddSi
ze-TSize+TASize) - 0.0293642*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[13]
              RobustAvgAddCost [14] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSi
ze-1100)^2)*TriDisModStdAddStd[13]
            }else
            {
              FlexAvgAddCost [14]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize
)-1100)^2)*TriDisModStdAddFlex[13]
              RobustAvgAddCost [14] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
            if(TSize>TMSize)
            {
              FlexMaxAddCost [14]   = (587770.49 + 255.30046*(TSize-TMSize) - 0.0342524*(
(TSize-TMSize)-1100)^2)*TriDisModStdAddStd[13]
              FlexMaxAddCost [14]   = FlexMaxAddCost [14] + (102596.39 + 96.037325*(AddSi
ze-TSize+TMSize) - 0.0293642*((AddSize-TSize+TMSize)-1100)^2)*TriDisModStdAddFlex[13]
              RobustMaxAddCost [14] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSi
ze-1100)^2)*TriDisModStdAddStd[13]
            }else
            {
              FlexMaxAddCost [14]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize
)-1100)^2)*TriDisModStdAddFlex[13]
              RobustMaxAddCost [14] = 0
            }
          } else
          {
            AddCost [14] = (762491.78 + 294.13388*AddSize - 0.0289768*(AddSize-1100)^2)*T
riDisModStdAddStd[13]

            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {
              FlexAvgAddCost [14]   = (762491.78 + 294.13388*(TSize-TASize) - 0.0289768*(
(TSize-TASize)-1100)^2)*TriDisModStdAddStd[13]
              FlexAvgAddCost [14]   = FlexAvgAddCost [14] + (120923.57 + 119.31587*(AddSi
ze-TSize+TASize) - 0.022339*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[13]
              RobustAvgAddCost [14] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSi
ze-1100)^2)*TriDisModStdAddStd[13]
            }else
            {
```

```
              FlexAvgAddCost [14]   = (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSi
ze)-1100)^2)*TriDisModStdAddFlex[13]
              RobustAvgAddCost [14] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
            if(TSize>TMSize)
            {
              FlexMaxAddCost [14]   = (762491.78 + 294.13388*(TSize-TMSize) - 0.0289768*(
(TSize-TMSize)-1100)^2 )*TriDisModStdAddStd[13]
              FlexMaxAddCost [14]   = FlexMaxAddCost [14] + (120923.57 + 119.31587*(AddSi
ze-TSize+TMSize) - 0.022339*((AddSize-TSize+TMSize)-1100)^2 )*TriDisModStdAddFlex[13]
              RobustMaxAddCost [14] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSi
ze-1100)^2)*TriDisModStdAddStd[13]
            }else
            {
              FlexMaxAddCost [14]= (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSize)
-1100)^2)*TriDisModStdAddFlex[13]
              RobustMaxAddCost [14] = 0
            }
          }
        } else
        {
          AddCost [14] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[13]

          'Determines addition Cost for average flexible and robust designs'
          if(TSize>TASize)
          {
            FlexAvgAddCost [14]   = (841127.96 + 208.01641*(TSize-TASize) - 0.0001798*((T
Size-TASize)-27413.8)^2 + 0.0000000010082*((TSize-TASize)-27413.8)^3)*TriDisModStdAddStd[
13]
            FlexAvgAddCost [14]   = FlexAvgAddCost [14] + (748729.11 + 267.12747*(AddSize
-TSize+TASize))*TriDisModStdAddFlex[13]
            RobustAvgAddCost [14] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[13]
          }else
          {
            FlexAvgAddCost [14]   = (748729.11 + 267.12747*AddSize)*TriDisModStdAddFlex[1
3]
            RobustAvgAddCost [14] = 0
          }
          'Determines addition Cost for max flexible and robust designs'
          if(TSize>TMSize)
          {
            FlexMaxAddCost [14]   = (841127.96 + 208.01641*(TSize-TMSize) - 0.0001798*((T
Size-TMSize)-27413.8)^2 + 0.0000000010082*((TSize-TMSize)-27413.8)^3)*TriDisModStdAddStd[
13]
            FlexMaxAddCost [14]   = FlexMaxAddCost [14] + (727335.73 + 308.56524*(AddSize
-TSize+TMSize) - 0.000058747*((AddSize-TSize+TMSize)-27413.8)^2)*TriDisModStdAddFlex[13]
```

```
            RobustMaxAddCost [14] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[13]
          }else
          {
            FlexMaxAddCost [14]   = (727335.73 + 308.56524*(AddSize) - 0.000058747*((AddS
ize)-27413.8)^2)*TriDisModStdAddFlex[13]
            RobustMaxAddCost [14] = 0
          }
        }
      } else
      {
        AddCost [14] = 0
        FlexAvgAddCost [14] = 0
        FlexMaxAddCost [14] = 0
        RobustAvgAddCost [14] = 0
        RobustMaxAddCost [14] = 0
      }
    } else
    {
      AddCost [14] = 0
      FlexAvgAddCost [14] = 0
      FlexMaxAddCost [14] = 0
      RobustAvgAddCost [14] = 0
      RobustMaxAddCost [14] = 0
    }

    '- Year 14 Predicted Costs'
    '---Annual operational costs for each facility Size'
    if(TSize<9000)
    {
      OpCost [15]     = (16765.308 + 13.883668*TSize)*TriDisOpYr14
      AvgOpCost [15]  = (16765.308 + 13.883668*TASize)*TriDisOpYr14
      MaxOpCost [15]  = (16765.308 + 13.883668*TMSize)*TriDisOpYr14
    } else
    {
      OpCost [15]     = (53423.187 + 10.373926*TSize)*TriDisOpYr14
      AvgOpCost [15]  = (53423.187 + 10.373926*TASize)*TriDisOpYr14
      MaxOpCost [15]  = (53423.187 + 10.373926*TMSize)*TriDisOpYr14
    }

    '---Modifications predicted in Lifecycle and their costs'
    '----HVAC Modification'
    'If statement determines if modification occurred it the set time period'
    if(HVAC19yrRandP<ModP_HVAC_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((HVAC7yrRandY<=0.8400) & (HVAC7yrRandY>0.8000))
```

```
      {
        if(NbrStories == 1)
        {
          HVACCostMean [15] = (171399.41 + 17.39759*TSize)*TriDisModHVACMean[14]
          HVACCostMedian [15] = (154855.44 + 3.81795606*TSize)*TriDisModHVACMedian[14]
        }
        else
        {
          HVACCostMean [15] = (196252.41 + 17.839797*TSize)*TriDisModHVACMean[14]
          HVACCostMedian [15] = (156490.77 + 3.9482492*TSize)*TriDisModHVACMedian[14]
        }

      } else
      {
        HVACCostMean [15] = 0
        HVACCostMedian [15] = 0
      }
    } else
    {
      HVACCostMean [15] = 0
      HVACCostMedian [15] = 0
    }
    '----COMM Modification'
    'If statement determines if modification occurred it the set time period'
    if(COMM19yrRandP<ModP_COMM_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((COMM19yrRandY<=0.8500) & (COMM19yrRandY>0.8500))
      {
        COMMCostMean [15] = (80771.311 + 7.2269841*TSize)*TriDisModCOMMMean[14]
        COMMCostMedian [15] = (85440.873 + 3.1165737*TSize)*TriDisModCOMMMedian[14]
      } else
      {
        COMMCostMean [15] = 0
        COMMCostMedian [15] = 0
      }
    }else
    {
      COMMCostMean [15] = 0
      COMMCostMedian [15] = 0
    }
    '----Electrical Modification'
    'If statement determines if modification occurred it the set time period'
    if(Elect19yrRandP<ModP_Elect_19)
    {
      'If Statement determines if the modification occured in this year and records the c
```

```
ost'
      if((Elect19yrRandY<=0.8966) & (Elect19yrRandY>0.8276))
      {
        ElectCostMean [15] = (72737.512 + 9.3469036*TSize)*TriDisModElectricMean[14]
        ElectCostMedian [15] = (76229.68 + 6.4750386*TSize)*TriDisModElectricMedian[14]
      } else
      {
        ElectCostMean [15] = 0
        ElectCostMedian [15] = 0
      }
    }else
    {
      ElectCostMean [15] = 0
      ElectCostMedian [15] = 0
    }
    '----Plumbing Modification'
    'If statement determines if modification occurred it the set time period'
    if(Plumb19yrRandP<ModP_Plumb_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Plumb19yrRandY<=0.9000) & (Plumb19yrRandY>1))
      {
        PlumbCostMean [15] = (80642.564 + 4.9662331*TSize)*TriDisModPlumbMean[14]
        PlumbCostMedian [15] = (86414.902 + 1.6289302*TSize)*TriDisModPlumbMedian[14]
      } else
      {
        PlumbCostMean [15] = 0
        PlumbCostMedian [15] = 0
      }
    } else
    {
      PlumbCostMean [15] = 0
      PlumbCostMedian [15] = 0
    }
    '----Facility Addition'
    'If statement determines if modification occurred it the set time period'
    if(Add19yrRandP<ModP_Add_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Add19yrRandY<=0.963) & (Add19yrRandY>0.8889))
      {
        'Random selection of addition size based on weibull distro'
        AddSize = rweibull(1, shape = 1.3062133, scale = 1742.5275)
        'Updates the facility size for a potential facility lifecycle'
        TSize = TSize + AddSize
```

```
        'Set logic statements to the new facility size'
        '-Standard Size less than 9K but greater than 4k'
        SizeLE9K    = if(TSize<=4000)    {0} else if (TSize<=9000) {1} else {0}
        'Updates modification that change when addition occurs'
        '-Standard Size'
        ModP_HVAC_19  = exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9K+3.95959468
*Code121+1.93840929*ModP_HVAC_7)/(1+exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9
K+3.95959468*Code121+1.93840929*ModP_HVAC_7))
        ModP_COMM_19  = exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeLE9K+3.8671011
5*Code675+2.21037167*ModP_COMM_8)/(1+exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeL
E9K+3.86710115*Code675+2.21037167*ModP_COMM_8))
        'Recodes the cost of the addition based on size and number of stories'
        if(AddSize <= 2000)
        {
          if(NbrStories == 1)
          {
            AddCost [15] = (587770.49 + 255.30046*AddSize - 0.0342524*(AddSize-1100)^2)*T
riDisModStdAddStd[14]
            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {
              FlexAvgAddCost [15]   = (587770.49 + 255.30046*(TSize-TASize) - 0.0342524*(
(TSize-TASize)-1100)^2 )*TriDisModStdAddStd[14]
              FlexAvgAddCost [15]   = FlexAvgAddCost [15] + (102596.39 + 96.037325*(AddSi
ze-TSize+TASize) - 0.0293642*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[14]
              RobustAvgAddCost [15] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSi
ze-1100)^2)*TriDisModStdAddStd[14]
            }else
            {
              FlexAvgAddCost [15]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize
)-1100)^2)*TriDisModStdAddFlex[14]
              RobustAvgAddCost [15] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
            if(TSize>TMSize)
            {
              FlexMaxAddCost [15]   = (587770.49 + 255.30046*(TSize-TMSize) - 0.0342524*(
(TSize-TMSize)-1100)^2)*TriDisModStdAddStd[14]
              FlexMaxAddCost [15]   = FlexMaxAddCost [15] + (102596.39 + 96.037325*(AddSi
ze-TSize+TMSize) - 0.0293642*((AddSize-TSize+TMSize)-1100)^2)*TriDisModStdAddFlex[14]
              RobustMaxAddCost [15] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSi
ze-1100)^2)*TriDisModStdAddStd[14]
            }else
            {
              FlexMaxAddCost [15]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize
)-1100)^2)*TriDisModStdAddFlex[14]
              RobustMaxAddCost [15] = 0
```

```
            }
          } else
          {
            AddCost [15] = (762491.78 + 294.13388*AddSize - 0.0289768*(AddSize-1100)^2)*T
riDisModStdAddStd[14]

            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {
              FlexAvgAddCost [15]   = (762491.78 + 294.13388*(TSize-TASize) - 0.0289768*(
(TSize-TASize)-1100)^2)*TriDisModStdAddStd[14]
              FlexAvgAddCost [15]   = FlexAvgAddCost [15] + (120923.57 + 119.31587*(AddSi
ze-TSize+TASize) - 0.022339*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[14]
              RobustAvgAddCost [15] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSi
ze-1100)^2)*TriDisModStdAddStd[14]
            }else
            {
              FlexAvgAddCost [15]   = (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSi
ze)-1100)^2)*TriDisModStdAddFlex[14]
              RobustAvgAddCost [15] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
            if(TSize>TMSize)
            {
              FlexMaxAddCost [15]   = (762491.78 + 294.13388*(TSize-TMSize) - 0.0289768*(
(TSize-TMSize)-1100)^2 )*TriDisModStdAddStd[14]
              FlexMaxAddCost [15]   = FlexMaxAddCost [15] + (120923.57 + 119.31587*(AddSi
ze-TSize+TMSize) - 0.022339*((AddSize-TSize+TMSize)-1100)^2 )*TriDisModStdAddFlex[14]
              RobustMaxAddCost [15] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSi
ze-1100)^2)*TriDisModStdAddStd[14]
            }else
            {
              FlexMaxAddCost [15]= (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSize)
-1100)^2)*TriDisModStdAddFlex[14]
              RobustMaxAddCost [15] = 0
            }
          }
        } else
        {
          AddCost [15] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[14]

          'Determines addition Cost for average flexible and robust designs'
          if(TSize>TASize)
          {
            FlexAvgAddCost [15]   = (841127.96 + 208.01641*(TSize-TASize) - 0.0001798*((T
Size-TASize)-27413.8)^2 + 0.0000000010082*((TSize-TASize)-27413.8)^3)*TriDisModStdAddStd[
14]
```

```
            FlexAvgAddCost [15]   = FlexAvgAddCost [15] + (748729.11 + 267.12747*(AddSize
-TSize+TASize))*TriDisModStdAddFlex[14]
            RobustAvgAddCost [15] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[14]
          }else
          {
            FlexAvgAddCost [15]   = (748729.11 + 267.12747*AddSize)*TriDisModStdAddFlex[1
4]
            RobustAvgAddCost [15] = 0
          }
          'Determines addition Cost for max flexible and robust designs'
          if(TSize>TMSize)
          {
            FlexMaxAddCost [15]   = (841127.96 + 208.01641*(TSize-TMSize) - 0.0001798*((T
Size-TMSize)-27413.8)^2 + 0.0000000010082*((TSize-TMSize)-27413.8)^3)*TriDisModStdAddStd[
14]
            FlexMaxAddCost [15]   = FlexMaxAddCost [15] + (727335.73 + 308.56524*(AddSize
-TSize+TMSize) - 0.000058747*((AddSize-TSize+TMSize)-27413.8)^2)*TriDisModStdAddFlex[14]
            RobustMaxAddCost [15] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[14]
          }else
          {
            FlexMaxAddCost [15]   = (727335.73 + 308.56524*(AddSize) - 0.000058747*((AddS
ize)-27413.8)^2)*TriDisModStdAddFlex[14]
            RobustMaxAddCost [15] = 0
          }
        }
      } else
      {
        AddCost [15] = 0
        FlexAvgAddCost [15] = 0
        FlexMaxAddCost [15] = 0
        RobustAvgAddCost [15] = 0
        RobustMaxAddCost [15] = 0
      }
    } else
    {
      AddCost [15] = 0
      FlexAvgAddCost [15] = 0
      FlexMaxAddCost [15] = 0
      RobustAvgAddCost [15] = 0
      RobustMaxAddCost [15] = 0
    }

    '- Year 15 Predicted Costs'
    '---Annual operational costs for each facility Size'
    if(TSize<9000)
    {
      OpCost [16]     = (17144.006 + 13.844214*TSize)*TriDisOpYr15
```

```
      AvgOpCost [16]  = (17144.006 + 13.844214*TASize)*TriDisOpYr15
      MaxOpCost [16]  = (17144.006 + 13.844214*TMSize)*TriDisOpYr15
    } else
    {
      OpCost [16]     = (45869.683 + 10.520963*TSize)*TriDisOpYr15
      AvgOpCost [16]  = (45869.683 + 10.520963*TASize)*TriDisOpYr15
      MaxOpCost [16]  = (45869.683 + 10.520963*TMSize)*TriDisOpYr15
    }

    '---Modifications predicted in Lifecycle and their costs'
    '----HVAC Modification'
    'If statement determines if modification occurred it the set time period'
    if(HVAC19yrRandP<ModP_HVAC_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((HVAC7yrRandY<=0.9600) & (HVAC7yrRandY>0.8400))
      {
        if(NbrStories == 1)
        {
          HVACCostMean [16] = (171399.41 + 17.39759*TSize)*TriDisModHVACMean[15]
          HVACCostMedian [16] = (154855.44 + 3.81795606*TSize)*TriDisModHVACMedian[15]
        }
        else
        {
          HVACCostMean [16] = (196252.41 + 17.839797*TSize)*TriDisModHVACMean[15]
          HVACCostMedian [16] = (156490.77 + 3.9482492*TSize)*TriDisModHVACMedian[15]
        }

      } else
      {
        HVACCostMean [16] = 0
        HVACCostMedian [16] = 0
      }
    } else
    {
      HVACCostMean [16] = 0
      HVACCostMedian [16] = 0
    }
    '----COMM Modification'
    'If statement determines if modification occurred it the set time period'
    if(COMM19yrRandP<ModP_COMM_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((COMM19yrRandY<=1) & (COMM19yrRandY>0.8500))
      {
```

```
        COMMCostMean [16] = (80771.311 + 7.2269841*TSize)*TriDisModCOMMMean[15]
        COMMCostMedian [16] = (85440.873 + 3.1165737*TSize)*TriDisModCOMMMedian[15]
      } else
      {
        COMMCostMean [16] = 0
        COMMCostMedian [16] = 0
      }
    }else
    {
      COMMCostMean [16] = 0
      COMMCostMedian [16] = 0
    }
    '----Electrical Modification'
    'If statement determines if modification occurred it the set time period'
    if(Elect19yrRandP<ModP_Elect_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Elect19yrRandY<=0.9310) & (Elect19yrRandY>0.8966))
      {
        ElectCostMean [16] = (72737.512 + 9.3469036*TSize)*TriDisModElectricMean[15]
        ElectCostMedian [16] = (76229.68 + 6.4750386*TSize)*TriDisModElectricMedian[15]
      } else
      {
        ElectCostMean [16] = 0
        ElectCostMedian [16] = 0
      }
    }else
    {
      ElectCostMean [16] = 0
      ElectCostMedian [16] = 0
    }
    '----Plumbing Modification'
    'If statement determines if modification occurred it the set time period'
    if(Plumb19yrRandP<ModP_Plumb_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Plumb19yrRandY<=1.000) & (Plumb19yrRandY>0.9000))
      {
        PlumbCostMean [16] = (80642.564 + 4.9662331*TSize)*TriDisModPlumbMean[15]
        PlumbCostMedian [16] = (86414.902 + 1.6289302*TSize)*TriDisModPlumbMedian[15]
      } else
      {
        PlumbCostMean [16] = 0
        PlumbCostMedian [16] = 0
      }
```

```
    } else
    {
      PlumbCostMean [16] = 0
      PlumbCostMedian [16] = 0
    }
    '----Facility Addition'
    'If statement determines if modification occurred it the set time period'
    if(Add19yrRandP<ModP_Add_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Add19yrRandY<=1) & (Add19yrRandY>0.963))
      {
        'Random selection of addition size based on weibull distro'
        AddSize = rweibull(1, shape = 1.3062133, scale = 1742.5275)
        'Updates the facility size for a potential facility lifecycle'
        TSize = TSize + AddSize
        'Set logic statements to the new facility size'
        '-Standard Size less than 9K but greater than 4k'
        SizeLE9K    = if(TSize<=4000)    {0} else if (TSize<=9000) {1} else {0}
        'Updates modification that change when addition occurs'
        '-Standard Size'
        ModP_HVAC_19  = exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9K+3.95959468
*Code121+1.93840929*ModP_HVAC_7)/(1+exp(-1.4422318-2.5173629*StoriesE1+1.82316545*SizeLE9
K+3.95959468*Code121+1.93840929*ModP_HVAC_7))
        ModP_COMM_19  = exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeLE9K+3.8671011
5*Code675+2.21037167*ModP_COMM_8)/(1+exp(-4.3576764+4.19570126*StoriesG2+2.31190654*SizeL
E9K+3.86710115*Code675+2.21037167*ModP_COMM_8))
        'Recodes the cost of the addition based on size and number of stories'
        if(AddSize <= 2000)
        {
          if(NbrStories == 1)
          {
            AddCost [16] = (587770.49 + 255.30046*AddSize - 0.0342524*(AddSize-1100)^2)*T
riDisModStdAddStd[15]
            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {
              FlexAvgAddCost [16]   = (587770.49 + 255.30046*(TSize-TASize) - 0.0342524*(
(TSize-TASize)-1100)^2 )*TriDisModStdAddStd[15]
              FlexAvgAddCost [16]   = FlexAvgAddCost [16] + (102596.39 + 96.037325*(AddSi
ze-TSize+TASize) - 0.0293642*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[15]
              RobustAvgAddCost [16] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSi
ze-1100)^2)*TriDisModStdAddStd[15]
            }else
            {
              FlexAvgAddCost [16]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize
```

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)-1100)^2)*TriDisModStdAddFlex[15]
              RobustAvgAddCost [16] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
            if(TSize>TMSize)
            {
              FlexMaxAddCost [16]   = (587770.49 + 255.30046*(TSize-TMSize) - 0.0342524*(
(TSize-TMSize)-1100)^2)*TriDisModStdAddStd[15]
              FlexMaxAddCost [16]   = FlexMaxAddCost [16] + (102596.39 + 96.037325*(AddSi
ze-TSize+TMSize) - 0.0293642*((AddSize-TSize+TMSize)-1100)^2)*TriDisModStdAddFlex[15]
              RobustMaxAddCost [16] = (587770.49 + 255.30046*(AddSize) - 0.0342524*(AddSi
ze-1100)^2)*TriDisModStdAddStd[15]
            }else
            {
              FlexMaxAddCost [16]= (102596.39 + 96.037325*(AddSize) - 0.0293642*((AddSize
)-1100)^2)*TriDisModStdAddFlex[15]
              RobustMaxAddCost [16] = 0
            }
          } else
          {
            AddCost [16] = (762491.78 + 294.13388*AddSize - 0.0289768*(AddSize-1100)^2)*T
riDisModStdAddStd[15]

            'Determines addition Cost for average flexible and robust designs'
            if(TSize>TASize)
            {
              FlexAvgAddCost [16]   = (762491.78 + 294.13388*(TSize-TASize) - 0.0289768*(
(TSize-TASize)-1100)^2)*TriDisModStdAddStd[15]
              FlexAvgAddCost [16]   = FlexAvgAddCost [16] + (120923.57 + 119.31587*(AddSi
ze-TSize+TASize) - 0.022339*((AddSize-TSize+TASize)-1100)^2)*TriDisModStdAddFlex[15]
              RobustAvgAddCost [16] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSi
ze-1100)^2)*TriDisModStdAddStd[15]
            }else
            {
              FlexAvgAddCost [16]   = (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSi
ze)-1100)^2)*TriDisModStdAddFlex[15]
              RobustAvgAddCost [16] = 0
            }
            'Determines addition Cost for max flexible and robust designs'
            if(TSize>TMSize)
            {
              FlexMaxAddCost [16]   = (762491.78 + 294.13388*(TSize-TMSize) - 0.0289768*(
(TSize-TMSize)-1100)^2 )*TriDisModStdAddStd[15]
              FlexMaxAddCost [16]   = FlexMaxAddCost [16] + (120923.57 + 119.31587*(AddSi
ze-TSize+TMSize) - 0.022339*((AddSize-TSize+TMSize)-1100)^2 )*TriDisModStdAddFlex[15]
              RobustMaxAddCost [16] = (762491.78 + 294.13388*(AddSize) - 0.0289768*(AddSi
ze-1100)^2)*TriDisModStdAddStd[15]
```

```
          }else
          {
            FlexMaxAddCost [16]= (120923.57 + 119.31587*(AddSize) - 0.022339*((AddSize)
-1100)^2)*TriDisModStdAddFlex[15]
            RobustMaxAddCost [16] = 0
          }
        }
      } else
      {
        AddCost [16] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[15]

        'Determines addition Cost for average flexible and robust designs'
        if(TSize>TASize)
        {
          FlexAvgAddCost [16]   = (841127.96 + 208.01641*(TSize-TASize) - 0.0001798*((T
Size-TASize)-27413.8)^2 + 0.0000000010082*((TSize-TASize)-27413.8)^3)*TriDisModStdAddStd[
15]
          FlexAvgAddCost [16]   = FlexAvgAddCost [16] + (748729.11 + 267.12747*(AddSize
-TSize+TASize))*TriDisModStdAddFlex[15]
          RobustAvgAddCost [16] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[15]
        }else
        {
          FlexAvgAddCost [16]   = (748729.11 + 267.12747*AddSize)*TriDisModStdAddFlex[1
5]
          RobustAvgAddCost [16] = 0
        }
        'Determines addition Cost for max flexible and robust designs'
        if(TSize>TMSize)
        {
          FlexMaxAddCost [16]   = (841127.96 + 208.01641*(TSize-TMSize) - 0.0001798*((T
Size-TMSize)-27413.8)^2 + 0.0000000010082*((TSize-TMSize)-27413.8)^3)*TriDisModStdAddStd[
15]
          FlexMaxAddCost [16]   = FlexMaxAddCost [16] + (727335.73 + 308.56524*(AddSize
-TSize+TMSize) - 0.000058747*((AddSize-TSize+TMSize)-27413.8)^2)*TriDisModStdAddFlex[15]
          RobustMaxAddCost [16] = (793066.85 + 204.49704*TSize)*TriDisModStdAddStd[15]
        }else
        {
          FlexMaxAddCost [16]   = (727335.73 + 308.56524*(AddSize) - 0.000058747*((AddS
ize)-27413.8)^2)*TriDisModStdAddFlex[15]
          RobustMaxAddCost [16] = 0
        }
      }
    } else
    {
      AddCost [16] = 0
      FlexAvgAddCost [16] = 0
      FlexMaxAddCost [16] = 0
```

```
        RobustAvgAddCost [16] = 0
        RobustMaxAddCost [16] = 0
      }
    } else
    {
      AddCost [16] = 0
      FlexAvgAddCost [16] = 0
      FlexMaxAddCost [16] = 0
      RobustAvgAddCost [16] = 0
      RobustMaxAddCost [16] = 0
    }

    '- Year 16 Predicted Costs'
    '---Annual operational costs for each facility Size'
    if(TSize<9000)
    {
      OpCost [17]     = (16337.326 + 14.136462*TSize)*TriDisOpYr16
      AvgOpCost [17]  = (16337.326 + 14.136462*TASize)*TriDisOpYr16
      MaxOpCost [17]  = (16337.326 + 14.136462*TMSize)*TriDisOpYr16
    } else
    {
      OpCost [17]     = (44598.959 + 10.600557*TSize)*TriDisOpYr16
      AvgOpCost [17]  = (44598.959 + 10.600557*TASize)*TriDisOpYr16
      MaxOpCost [17]  = (44598.959 + 10.600557*TMSize)*TriDisOpYr16
    }
    '---Modifications predicted in Lifecycle and their costs'
    '----HVAC Modification'
    'If statement determines if modification occurred it the set time period'
    if(HVAC19yrRandP<ModP_HVAC_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((HVAC7yrRandY<=1) & (HVAC7yrRandY>0.9600))
      {
        if(NbrStories == 1)
        {
          HVACCostMean [17] = (171399.41 + 17.39759*TSize)*TriDisModHVACMedian[16]
          HVACCostMedian [17] = (154855.44 + 3.81795606*TSize)*TriDisModHVACMedian[16]
        }
        else
        {
          HVACCostMean [17] = (196252.41 + 17.839797*TSize)*TriDisModHVACMedian[16]
          HVACCostMedian [17] = (156490.77 + 3.9482492*TSize)*TriDisModHVACMedian[16]
        }

      } else
      {
```

```
        HVACCostMean [17] = 0
        HVACCostMedian [17] = 0
      }
    } else
    {
      HVACCostMean [17] = 0
      HVACCostMedian [17] = 0
    }
    '----COMM Modification'
    'If statement determines if modification occurred it the set time period'
    # None after year 15
    COMMCostMean [17] = 0
    COMMCostMedian [17] = 0
    '----Electrical Modification'
    'If statement determines if modification occurred it the set time period'
    if(Elect19yrRandP<ModP_Elect_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Elect19yrRandY<=0.9310) & (Elect19yrRandY>0.9310))
      {
        ElectCostMean [17] = (72737.512 + 9.3469036*TSize)*TriDisModElectricMean[16]
        ElectCostMedian [17] = (76229.68 + 6.4750386*TSize)*TriDisModElectricMedian[16]
      } else
      {
        ElectCostMean [17] = 0
        ElectCostMedian [17] = 0
      }
    }else
    {
      ElectCostMean [17] = 0
      ElectCostMedian [17] = 0
    }
    '----Plumbing Modification'
    'If statement determines if modification occurred it the set time period'
    # None after year 15
    PlumbCostMean [17] = 0
    PlumbCostMedian [17] = 0
    '----Facility Addition'
    # None after year 15
    AddCost [17] = 0
    FlexAvgAddCost [17] = 0
    FlexMaxAddCost [17] = 0
    RobustAvgAddCost [17] = 0
    RobustMaxAddCost [17] = 0
    '- Year 17 Predicted Costs'
    '---Annual operational costs for each facility Size'
```

```
    if(TSize<9000)
    {
      OpCost [18]     = (16696.501 + 14.115312*TSize)*TriDisOpYr17
      AvgOpCost [18]  = (16696.501 + 14.115312*TASize)*TriDisOpYr17
      MaxOpCost [18]  = (16696.501 + 14.115312*TMSize)*TriDisOpYr17
    } else
    {
      OpCost [18]     = (46788.937 + 10.592369*TSize)*TriDisOpYr17
      AvgOpCost [18]  = (46788.937 + 10.592369*TASize)*TriDisOpYr17
      MaxOpCost [18]  = (46788.937 + 10.592369*TMSize)*TriDisOpYr17
    }

    '---Modifications predicted in Lifecycle and their costs'
    '----HVAC Modification'
    'If statement determines if modification occurred it the set time period'
    # None after year 15
    HVACCostMean [18] = 0
    HVACCostMedian [18] = 0
    '----COMM Modification'
    # None after year 15
    COMMCostMean [18] = 0
    COMMCostMedian [18] = 0
    '----Electrical Modification'
    'If statement determines if modification occurred it the set time period'
    if(Elect19yrRandP<ModP_Elect_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Elect19yrRandY<=0.9655) & (Elect19yrRandY>0.9310))
      {
        ElectCostMean [18] = (72737.512 + 9.3469036*TSize)*TriDisModElectricMean[17]
        ElectCostMedian [18] = (76229.68 + 6.4750386*TSize)*TriDisModElectricMedian[17]
      } else
      {
        ElectCostMean [18] = 0
        ElectCostMedian [18] = 0
      }
    }else
    {
      ElectCostMean [18] = 0
      ElectCostMedian [18] = 0
    }
    '----Plumbing Modification'
    # None after year 15
    PlumbCostMean [18] = 0
    PlumbCostMedian [18] = 0
    '----Facility Addition'
```

```
    # None after year 15
    AddCost [18] = 0
    FlexAvgAddCost [18] = 0
    FlexMaxAddCost [18] = 0
    RobustAvgAddCost [18] = 0
    RobustMaxAddCost [18] = 0
    '- Year 18 Predicted Costs'
    '---Annual operational costs for each facility Size'
    if(TSize<9000)
    {
      OpCost [19]     = (17586.624 + 13.99945*TSize)*TriDisOpYr18
      AvgOpCost [19]  = (17586.624 + 13.99945*TASize)*TriDisOpYr18
      MaxOpCost [19]  = (17586.624 + 13.99945*TMSize)*TriDisOpYr18
    } else
    {
      OpCost [19]     = (51920.552 + 10.488268*TSize)*TriDisOpYr18
      AvgOpCost [19]  = (51920.552 + 10.488268*TASize)*TriDisOpYr18
      MaxOpCost [19]  = (51920.552 + 10.488268*TMSize)*TriDisOpYr18
    }
    '---Modifications predicted in Lifecycle and their costs'
    '----HVAC Modification'
    # None after year 15
    HVACCostMean [19] = 0
    HVACCostMedian [19] = 0
    '----COMM Modification'
    # None after year 15
    COMMCostMean [19] = 0
    COMMCostMedian [19] = 0
    '----Electrical Modification'
    'If statement determines if modification occurred it the set time period'
    if(Elect19yrRandP<ModP_Elect_19)
    {
      'If Statement determines if the modification occured in this year and records the c
ost'
      if((Elect19yrRandY<=1) & (Elect19yrRandY>0.9655))
      {
        ElectCostMean [19] = (72737.512 + 9.3469036*TSize)*TriDisModElectricMean[18]
        ElectCostMedian [19] = (76229.68 + 6.4750386*TSize)*TriDisModElectricMedian[18]
      } else
      {
        ElectCostMean [19] = 0
        ElectCostMedian [19] = 0
      }
    }else
    {
      ElectCostMean [19] = 0
      ElectCostMedian [19] = 0
```

```
    }
    '----Plumbing Modification'
    # None after year 15
    PlumbCostMean [19] = 0
    PlumbCostMedian [19] = 0
    '----Facility Addition'
    # None after year 15
    AddCost [19] = 0
    FlexAvgAddCost [19] = 0
    FlexMaxAddCost [19] = 0
    RobustAvgAddCost [19] = 0
    RobustMaxAddCost [19] = 0


'Modification Costs'
'-- Standard Design'
    ModCostMedian       = HVACCostMedian + COMMCostMedian + ElectCostMedian + PlumbCostMe
dian
    ModCostMean         = HVACCostMean   + COMMCostMean   + ElectCostMean   + PlumbCostMe
an

'LCC of each design'
    LCStdTotCostMedian[i]  = sum(OpCost,ModCostMedian,AddCost)+IntStdCost
    LCStdTotCostMean[i]    = sum(OpCost,ModCostMean,AddCost)+IntStdCost
    LCFlexAvgTotCost[i]    = sum(OpCost,FlexAvgAddCost)+IntFlexAvgCost
    LCFlexMaxTotCost[i]    = sum(OpCost,FlexMaxAddCost)+IntFlexMaxCost
    LCRobAvgTotCost[i]     = sum(AvgOpCost,RobustAvgAddCost)+IntRobustAvgCost
    LCRobMaxTotCost[i]     = sum(MaxOpCost,RobustMaxAddCost)+IntRobustMaxCost


  } #end of lifecycle loop
```

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14. ABSTRACT

The purpose of this research is to ascertain the type of facility design, standard, robust, or flexible, that yields the greatest lower lifecycle costs (LCC) savings to the USAF. To this aim, the researcher constructed a Monte Carlo simulation to determine the LCC for flexible, robust, and standard administrative facility designs for thousands of potential facility lifecycles. The simulation also illustrates the circumstances under which each type of design would result in the lowest LCC. The results of this research will show the USAF the importance of focusing on LCC and designing flexible facilities. Standard and robust designs are the staples of the current practice. This research found implementing flexible facility design into practice is advantageous to the United States Air Force (USAF) for two key reasons: (1) Flexible designs allows USAF facilities to easily adapt to changes in user demands and, (2) when compared to both standard and robust designs, flexible designs have LCC.

15. SUBJECT TERMS
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