INVESTIGATION OF THE INTEGRATION OF INTERSTITIAL BUILDING SPACES ON COSTS AND TIME OF FACILITY MAINTENANCE FOR U.S. ARMY HOSPITALS

A Thesis

by

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ABSTRACT

The U.S. Army Medical Department (AMEDD) has used the interstitial building system (IBS) as a design component for some of the hospitals in its healthcare infrastructure portfolio. Department of Defense (DoD) leadership is aware of increases in healthcare costs and understands the importance of safely reducing costs, which may be possible through design initiatives. An analysis was performed on facility maintenance metrics for ten different U.S. Army hospitals, including IBS design and conventional / non-interstitial building system (NIBS) design.

Statistical analysis indicated a significant difference in cost and time data between IBS and NIBS for most of the building systems considered (HVAC, electrical, plumbing, and interior). Scheduled maintenance for the plumbing building system was not found to have a significant difference in costs; scheduled maintenance for the HVAC and plumbing building system was not found to have a significant difference in time expended. The data in this study showed that facility maintenance cost and time were generally lower for IBS than NIBS. Time spent (and associated cost) for scheduled maintenance of the electrical and plumbing building systems were slightly higher in IBS, though not significantly higher for plumbing. It may be easier to reach the plumbing and electrical building systems due to the greater accessibility afforded by IBS design.

While a cost premium is estimated for integrating IBS design, the savings provided by life cycle facility maintenance is estimated to be up to three and a half times the initial cost premium.

DEDICATION

To Leo vom Elzmündungsraum

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NOMENCLATURE

ACF	Area Cost Factor
ACH	Army Community Hospital
AIA	The American Institute of Architects
AMC	Army Medical Center
AMEDD	U.S. Army Medical Department
BAMC	Brook Army Medical Center
CCI	City Cost Index
DMLSS	Defense Medical Logistics Standard Support
DoD	Department of Defense
DTA	Decision Tree Analysis
FM	Facility Management
FMSOC	Facility Management Support Operations Center
GAO	U.S. Government Accountability Office
HAI	Healthcare Associated Infection
HVAC	Heating, Ventilation, & Air Conditioning
IBS	Interstitial Building Space
ICRA	Infection Control Risk Assessment
JMAR	Joint Medical Asset Repository
MHS	Military Healthcare System
MILCON	Military Construction

NIBS	Non Interstitial Building Space
NPV	Net Present Value
O&M	Operations & Maintenance
PDC	Planning, Design, & Construction
PMI	Project Management Institute
R^2	Coefficient of Determination
RCM	Reliability Centered Maintenance
SAMMC	San Antonio Military Medical Center
SAR	System Access Request
SRM	Sustainment, Restoration, & Modernization
UFC	Unified Facilities Criteria
VA	Veterans Administration
WBDG	Whole Building Design Guide

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1. INTRODUCTION

This study focuses on a comparison of interstitial building system (IBS) design with that of a conventional hospital (non interstitial building system) design by analyzing costs and time spent on facility maintenance for ten U.S. Army hospitals over a fifteen year period. Many designers in the private sector currently believe an IBS hospital is far more expensive than non-interstitial. Yet, despite the perceived cost premiums, many benefits are believed to be realized through selection of the IBS design method.

Largely due to separation of zones, IBS design is thought to offer advantages in infection control, reducing the potential for acquiring healthcare associated infections (HAI); in flexibility, maximizing the potential to adapt to technological changes; in disruption, reducing the potential to impact daily clinical operations; in construction, maximizing the potential to most effectively employ various crews; and in maintenance, minimizing the costs and time associated with facility maintenance.

The data acquired during the course of this research permits an analysis of the last benefit described: more efficient facility maintenance. However, each of the other areas is worth further investigation. Evidence obtained from further investigation can not only validate potential advantages, but also can offer a greater awareness to the true costs of design decisions being made.

The U.S. Government Accountability Office (GAO) reported that the military healthcare system (MHS) is "projected to reach nearly $95 billion by 2030" and that the increases of healthcare costs in the defense budget resulted in “current DoD leadership and Congress [to] have recognized the need to better control these costs” (GAO 2012). However, the report acknowledges that “personnel cost savings” was the only area that was estimated in analyzing the “implementation costs and anticipated savings associated with the creation of the shared services part of the Defense Health Agency” and that estimates should be performed in other areas (GAO 2012).

The other areas include “implementation costs (personnel severance, moving, military construction, and information technology) and cost savings (shared services, health care operations, and reduced infrastructure)” (GAO 2012). Regardless of MHS management models, the same rationale could be applied to reducing costs for the DoD’s current and future health care infrastructure. Improvements in infection control could affect costs for shared services, health care operations, and personnel. Improvements in flexibility could affect costs for moving, military construction, information technology, and health care operations. Minimizing disruption could affect costs for shared services, health care operations, and personnel. Improvements in construction efficiency or reduced construction schedules could affect costs in military construction. Finally, improvements in facility maintenance efficiencies could affect costs for health care operations and personnel helping to reduce an O&M budget.

IBS offers the potential to provide for these types of improvements.

2. LITERATURE REVIEW

2.1. Interstitial Building Spaces (IBS)

IBS can be described as an "unfinished or non-habitable" support or service space in between two functional or operational spaces or zones that "permits locating the majority of facility utility distribution and terminal equipment within the interstitial space" (DoD 2012; Joint Venture 1977). The purpose of the service zone is to provide building systems with dedicated and accessible space while minimizing disruption to the functional zone. The building systems can include mechanical, electrical, plumbing, and information technology infrastructure. In terms of a health care facility, the service floor between two clinical floors might also house hospital pneumatic tube systems. IBS dimensions can vary, but a study conducted for the Veterans Administration (VA) recommends eight to nine feet height in the service zone so that it is "of sufficient size to accommodate [workers]" (Joint Venture 1977).

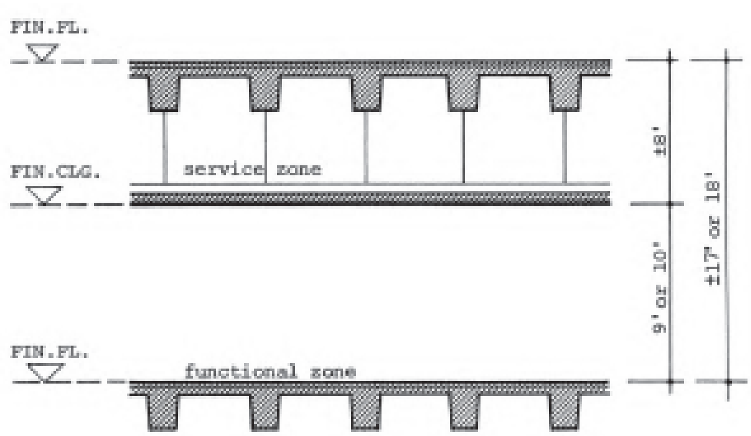


Figure 1. IBS Zones (Joint Venture 1977)

As of this writing, the Department of Defense (DoD) prescribes two alternatives in IBS design: systems module concept and non-modular concept. The primary difference is what functional zones are supported by the service zone. The systems module concept (Figure 2) has a "dedicated utility pod" to support one occupancy boundary, which is limited to 22,500 square feet while the non-modular concept can "serve different (multiple) functional areas, occupancies, or compartments" (DoD 2012).

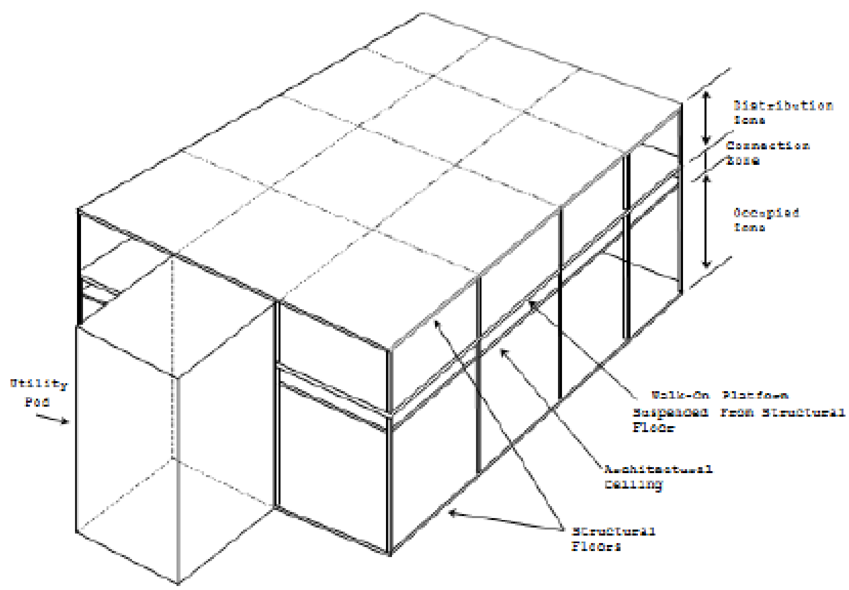


Figure 2. Areas of IBS Systems Module Concept (DoD 2012)

For the DoD, the "walk-on platform" of the service or distribution zone is not considered a separate floor of the building; the Unified Facilities Criteria (UFC) also list specific requirements for mechanical and plumbing, electrical and communications equipment, fire protection, and documentation and construction considerations (Figure

3) (DoD 2012). Construction considerations of IBS design are only one element that impacts a health care facility.

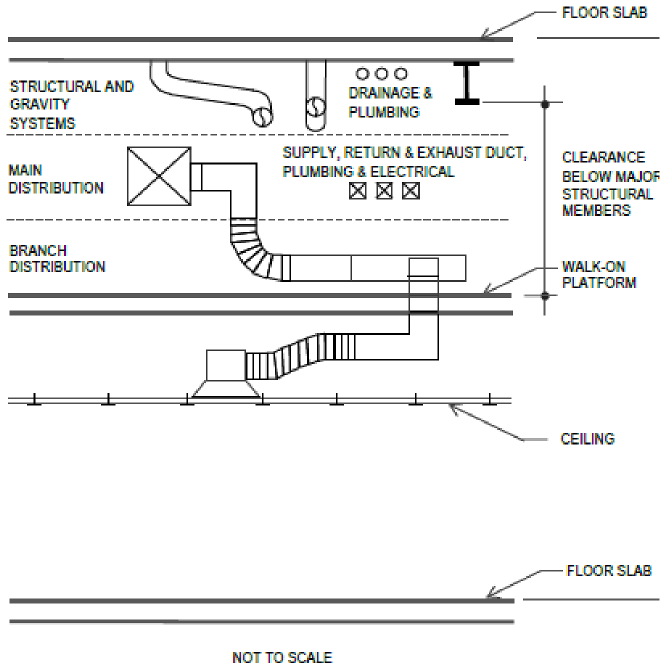


Figure 3. Arrangement of IBS Elements (DoD 2012)

2.2. IBS Design Rationale for Health Care Facilities

There are several key reasons for selecting IBS design for a health care facility including the "convenient installation, maximizing utility access and maintainability, providing for future building flexibility, [and] minimizing disruption to medical or laboratory services" (Figure 4) (DoD 2012). Each of these reasons has the potential to provide cost savings, time savings, and improved quality of care. Cost savings could be obtained from reduced construction timelines, greater flexibility, and lower maintenance costs. Time savings could impact costs in terms of reduced labor and less rework for maintenance. Costs could also be impacted by improved quality of care provided for the patients, staff, families and visitors due to less disruption. This could be in terms of metrics such as better patient outcomes, lower rates of healthcare associated infections, lower numbers of patients readmitted, and lower levels of stress.

Figure 4. IBS Accessibility (DoD 2012)

The hospital built environment is likely to influence the potential for healthcare associated infections due to reservoirs for microorganisms that can be transmitted to others (Casey et al. 2010). Environmental surfaces in healthcare built environments can contribute to transmitting pathogens that can adversely affect health outcomes (Gillespie et al 2012). The relationship between the built environment and health outcomes is documented (Figure 5) (Codinhoto et al. 2009).

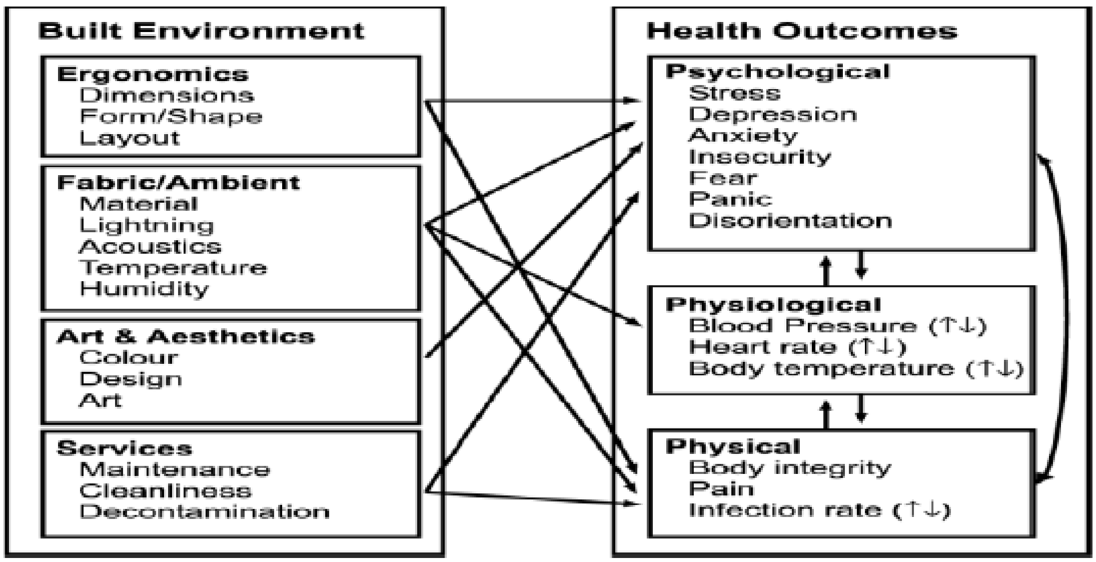


Figure 5. Relationship Between Built Environment and Health Outcomes (Codinhoto et al. 2009)

2.2.1. Infection Control

Construction-related infection control issues include dust generation, duration of activity, work conducted over continuous shifts, air handler interruptions, isolating the construction/renovation area, project complexity, proximity to patients, daily demolition removal affecting traffic patterns, vibration, contamination of mechanical systems including medical vacuum from power interruptions (Bartley 2000).

The level of required barriers impacts the determination if there is a major or minor risk. Although a small project requires sealing only fire-rated plastic sheeting, a larger more complex project requires sealing rigid, dust-proof, fire-rated barrier walls. Additionally, there may be a requirement for entry vestibules with gasket door frames. At the end of the project, these must all be properly removed (Bartley 2000). Since hospital renovation projects are part of the facility life cycle plan, and because zones of separation are required during the renovation (minor sustainment construction, modernization, or repair works), it appears that a type of interstitial space will be temporarily placed in different parts of the hospital at different times in the life cycle. Rather than many temporary interstitial spaces over time, a complete IBS design may offer in both cost savings and reduced risk of contamination due to problems such as have been discussed in the literature.

2.2.1.1. Case Study – Hospital in Japan

An 11-story, 602-bed hospital originally constructed in 1976 (presumably in Japan) had a major renovation package from 1999 to 2004. During this five year period they added a new building (150% increase in floor surface) and renovated the existing building and installed temporary walls to separate construction areas from clinical areas in use. The project included modifying the heating system to also provide air conditioning. The following year after construction was completed there were bacteria cases were verified by positive blood cultures. They found that although there had been previous cases even in 2000, there was an increasing trend since 2002. The first phase had been the new construction from 1999-2001, and after this started the mixing of renovation work with typical hospital work being performed in the same building. Based upon the location of the cases and the location of the renovation work, they felt the renovation work probably caused dust accumulation containing the bacteria. The other possible sources they reported were air filtration system, ventilator equipment, dressing, gloves, hands of healthy staff, intravenous catheters, alcohol-based hand-wash solutions, specimen collection tubes, blood culture media and linens (Ohsaki et al. 2007).

The effectiveness of temporary barriers can be questioned. The renovation work took about the same amount of time as the new construction, assuming new construction started in January 1999. During the years of renovation there was a trend increase in cases of positive blood samples of bacteria that endemically resides in dust. They also found colonies in clean towels and gowns. The facility was in operation for about 23 years before this major construction project. The project took about 5 years. During this time they had to put up temporary barriers. As of this writing, it was not determined what the expected life cycle is for health facilities in Japan. From 1976 to 2004, over 17% of the life cycle was under this major project.

2.2.1.2. Case Study – Hospital in Houston, Texas

Another study reported on a bacteria outbreak in 2007 in a 275-bed NICU in Houston, Texas during a construction project. An investigation showed that bioaerosol and surface contamination was evident. They suspected that contamination came from air filters and the loading dock which was close to the excavation site. After the loading dock was relocated no other cases were detected. It was suspected that construction may have been a contributing factor (Campbell et al. 2011).

Infection control measures are meant to help ensure the safety and efficacy of the clinical setting and help prevent escalating costs, and thus the quality of the healthcare delivered with the aims of improving patient outcomes. “A study of hospital-acquired infections done by the state of Pennsylvania and published in 2006 showed insurers paid an average of $53,915 for hospitalization of an infected patient compared to $8,311 for patients without infection” (Ashton 2009). Stakeholders should seek information, data, or evidence which supports such aims through all phases of the facility life cycle. Design decisions must be reflective of specific and measurable controls that seek to maximize the quality of healthcare delivered while minimizing costs and time spent on both on facility maintenance as well as hospital operations in general.

2.2.2. Flexibility

Hospital programming requirements are constantly changing and one of the primary reasons is due to technological advances. Due to the nature of change in healthcare delivery, it is imperative that adaptability or flexibility of the facility is maximized. IBS design allows different departments within the hospital to more easily adapt to these changes with less disruption as renovation work is performed over the lifecycle of the facility. Future change can include equipment upgrades or modifications due to lifecycle replacements, technology advances, or impacts from operational mission changes such as a movement to decrease the number of inpatient beds with changes in healthcare trends.

2.2.3. Disruption

IBS design could provide a lowered inconvenience to patients, clinical and administrative staff and increased accessibility for maintenance staff. This can result in minimizing disruption and maximizing cost savings (MacKenzie 1992).

2.2.4. Construction

Construction timelines are likely to be reduced for various reasons, including that crews performing work in the functional zone will be less disrupted by crews installing equipment and performing other works in the service zone. The VA study cites the key to time savings during construction as the "separation of rough and finish trades by means of the ceiling-platform and the provision of reserved zones for each service" (Joint Venture 1977).

Construction can impact the levels of microorganisms that are dispersed during the construction, renovation, or repair activities. Piping running directly above ceiling tiles or in walls loses a protective layer that could be provided by IBS design, and could lead to additional problems such as leaking that could cause unnecessary damage to floors, walls, and ceilings. Other factors could include fireproofing insulation, window air conditioners, false ceilings, construction activity, ventilation duct fiberglass insulation, air filters, ceiling tiles, renovation works, soil residues, water damages, vent system humidifier, and others (Bartley 2000).

2.2.5. Maintenance

Accessibility to perform scheduled and unscheduled maintenance impacts building performance. Decreases in accessibility can result in a sub-optimum building performance and can limit future adaptability of the facility.

Performing maintenance in a clinical room wall or above a ceiling tile could provide a greater opportunity for pathogens to contaminate patients and staff or floors, walls, surfaces, and other equipment in the room as scheduled or unscheduled maintenance of the building equipment systems are performed (Joint Venture 1977).

The Army Medical Department (AMEDD) has recently adopted Reliability Centered Maintenance (RCM) in its preventive maintenance policies and procedures. "Reliability is the probability that a device will satisfactorily perform a specified function for a specified period of time under given operating conditions" (Smith and Hinchcliffe 2004). In reviewing existing literature for RCM, the fallacy of the bathtub effect was identified. The bathtub effect states that there is a greater assumed liability or failure at the beginning and end of the lifecycle. Studies from 1968, 1973, and 1982 each reported a fallacy to the bathtub effect (Smith and Hinchcliffe 2004).

Comparing the maintenance of hospitals with and without IBS design could provide indicators that can help planners make decisions on the future of world-class healthcare.

2.3. Decision Making Process in Selecting IBS Design

Many factors are considered in the decision making process when selecting whether to use IBS design for a health care facility.

2.3.1. Stakeholders and Project Life Cycles

Stakeholders can influence leadership who make the decision whether to integrate IBS design into a health care facility. Stakeholders are “persons or organizations… who are actively involved in the project or whose interests may be positively or negatively affected by the performance or completion of a project” (PMI 2008).

The users of a hospital include patients, staff, and family and visitors and they are among some of the stakeholders that are involved in the various projects that occur during the facility life cycle of a hospital. Each offer a different set of influences that can impact costs of design changes over time and impact design decisions based upon past experiences.

The Project Management Institute (PMI) demonstrates the relationship between stakeholder influences, risk, and uncertainty with the cost of changes over time (Figure 6). This shows that costs are lower and influence is higher at the beginning of a project and infers that hospital design decisions or changes are more costly as time progresses.

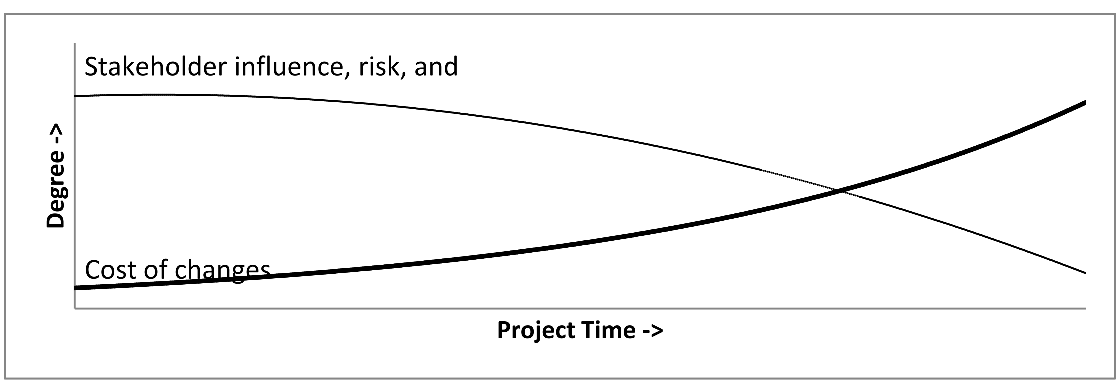


Figure 6. Cost Influence Curve (adapted from PMI 2008)

The phases of a project life cycle include performing business planning, performing pre-project planning, executing the project, and operating the facility (CII No Date). The relationship between a project life cycle and a facility life cycle can be better understood by considering the types of facility or building projects that a hospital might undergo. It is said that "structuring projects with distinct phases and responsibilities can increase risk by isolating the project participants in such a manner that minimal attention is given to overarching project concerns" (Walewski 2005); therefore, it is important to remain cognizant of the impacts of all phases of a project lifecycle, not just initial construction.

For the DoD, three types of facility projects are typically performed for the military's health care facilities. The first is military construction (MILCON). The second is operations and maintenance (O&M). The third is major renovations or repairs, sometimes referred to as sustainment, restoration, and modernization (SRM).

2.3.2. Planning, Design, and Construction (PDC)

In a report on building maintenance and repair data, the U.S. Army Corps of Engineers reports that "in the facility life-cycle process, costs are incurred in construction, operation, maintenance, and disposal of a facility. Past emphasis during the planning, design, and construction phases has been on estimating initial construction costs. The impact of operating and maintaining facilities has always been a secondary consideration. In many cases, the operation and maintenance (O&M) costs are far greater than initial construction costs. Building owners are "concerned with the total ownership costs of facilities rather than just the initial construction costs" (Neely et al.

1991). This means that even back in 1991, owners were identifying the importance of making design decisions for total costs, not just initial costs.

Yet in speaking with many healthcare architects and designers today, design decisions are sometimes discussed in terms of first cost premiums of which the perception still exists that owners are not able or willing to fund.

"Traditionally, operating and maintenance costs of construction were not taken into account. However, the relationship of capital and maintenance costs can take the ratio of… up to 1:5… [so] it is extremely important to design new facilities in a way to reduce the overall life cycle cost without reduction of the quality of construction. On the contrary, installation of quality elements should provide better functionality and lower building maintenance costs during its life time period…" (Marenjak and Krstic 2010). Marenjak and Krstic bring up a key issue: quality elements should help reduce costs.

"In a healthcare setting facility maintenance issues are particularly important perhaps more than most other building types since such settings are acutely sensitive to construction and renovation activities, and dust and airborne particulates contributing to serious health and safety concerns are well documented" (Pati et al. 2010). Pati et al. discuss the disconnects and associated impacts of the disconnects between two processes in a facility life cycle: facility design and facility maintenance. They relate quality considerations regarding safety to facility design and maintenance. The American Institute of Architects (AIA) Guidelines requirement for Infection Control Risk Assessment (ICRA) is meant to integrate infection control input into the early planning of a health facility construction project. Involved personnel must identify, assess, assign, and publish roles and responsibilities for major areas of concern during the project. These may include plans for: facility and subcontractor coordination for all phases of construction, facility patient unit closure, mechanical systems, contractor accountability, risk assessment, occupational health, traffic patterns, waste disposal, and emergency preparedness (Bartley 2000). Another area is education, but it is important to identify the learning objectives and the audience targeted for education.

Design decisions from time, cost, and quality considerations must be integrated into the PDC process and should be based upon data, or evidence, rather than anecdote. A clear definition as described from Professor Hamilton, "Evidence-based design is a process for the conscientious, explicit, and judicious use of current best evidence from research and practice in making critical decisions, together with an informed client, about the design of each individual and unique project" (Hamilton and Watkins 2009).

2.3.3. Feedback and Performance Evaluation

In order to fully support planning and design decisions, leaders must have accurate, complete, and timely information to make those decisions. The information must systematically undergo an analysis which includes, at a minimum, a review of priorities, limitations, constraints, facts, assumptions, and risk assessments. This information must be monitored throughout a hospital's facility life cycle. This means that past experiences, or history, have to be used starting from the phase of performing business planning through the phase of operating the facility (including decommissioning). Simply put, to be able to adequately use that information, it must first be captured. Secondly, and probably more importantly, it must be shared or available for stakeholders who prepare analyses and leaders who make decisions.

Although facility managers, while conducting facility management (FM), are typically most knowledgeable about the historical information of their respective hospital, the transition of that knowledge to business planners can be lost. "The FM processes required for a construction project are at times so complex that it is hard for the planning team to integrate them. The list of services identified for FM planning is therefore often incomplete, and specialists are insufficiently integrated during the planning and construction phases. FM planning is complex, construction teams are interdisciplinary, and participants' expertise varies greatly" (von Felten et al. 2009). To combat these challenges, tools such as von Felten's et al. 'FM-Dashboard,' have been developed.

Yet the idea of tool development is not new. The Construction Industry Institute systematically performs research to determine best practices and create tools to help leverage those best practices in order to "improve construction cost effectiveness" and achieve "successful project performance" (Anderson 1989).

Costs of using IBS design are not always well documented. It has been reported there is a 2-2.5% first cost premium on at least one VA study (Post and Kohn 1995). However, total costs must be considered, assuming the 1:5 ratio of capital to maintenance costs (Marenjak and Krstic 2010). These costs must be captured for all phases of the facility life cycle, and specifically for efforts in MILCON, O&M, and SRM.

The disconnect may then lie not in the ability to utilize tools to successfully monitor the facility life cycle, but in the ability to effectively communicate, emphasize, and execute priorities which would support tool utilization. As a result, this research is an effort to investigate the integration of IBS into U.S. Army hospitals.

2.4. Research Questions and Hypotheses

The literature covers a diverse set of topics which are related to operations and maintenance in health care facilities. There are many possible reasons for selecting IBS design as a real option for health care facilities. Therefore, it is necessary to quantify the benefits of integrating IBS design. To test the potential benefits of IBS design in health care facilities, the following questions and hypotheses were developed:

2.4.1. Quality

Is there any difference in quality due to disruptions of care provided between a hospital that has interstitial building spaces and a hospital without interstitial building spaces?

H_{01}: No difference exists between hospitals with interstitial building spaces and hospitals without interstitial building spaces regarding the quality of care provided due to disruptions.

$$H_{0_1}: \mu_{IBS} = \mu_{NIBS}$$

H_{a1}: A hospital with interstitial building spaces provides less disruption and thus better quality of care than a hospital without interstitial building spaces.

$$H_{a_1}: \mu_{IBS} < \mu_{NIBS}$$

2.4.2. Cost

Is there any difference in maintenance costs between a hospital that has interstitial building spaces and a hospital without interstitial building spaces?

H_{02}: No difference exists between hospitals with interstitial building spaces and hospitals without interstitial building spaces regarding the cost to maintain the facility.

$$H_{0_2}: \mu_{IBS} = \mu_{NIBS}$$

H_{a2}: A hospital with interstitial building spaces costs less to maintain than a hospital without interstitial building spaces.

$$H_{a_2}: \mu_{IBS} < \mu_{NIBS}$$

2.4.3. Time

Is there any difference in time required for maintenance between a hospital that has interstitial building spaces and a hospital without interstitial building spaces?

H_{03}: No difference exists between hospitals with interstitial building spaces and hospitals without interstitial building spaces regarding the cost to maintain the facility.

$$H_{0_3}: \mu_{IBS} = \mu_{NIBS}$$

H_{a3}: A hospital with interstitial building spaces takes less time to maintain than a hospital without interstitial building spaces.

$$H_{a_3}: \mu_{IBS} < \mu_{NIBS}$$

3. METHODS

3.1. Introduction

The purpose of this section is to discuss the research design, data collection and analysis methodologies that were used through the course of this study.

3.2. Research Design

In order to help best answer the research questions posed, various research processes were reviewed and evaluated, and the decision was made to perform a quantitative analysis on existing and available data (Leedy and Ormrod 2010; Naoum 2013). Each step of the process provides feedback to the current knowledge base and encourages additional guidance and review of literature (Figure 7).

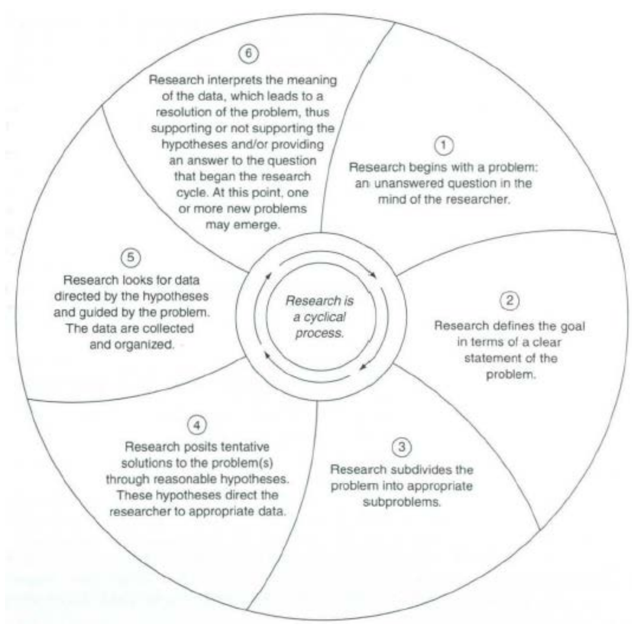


Figure 7. The Research Process (Leedy and Ormrod 2010)

It was of interest to consider the relationships of an aspect of the building design with an aspect of quality, cost, and time. Thus a descriptive research, comparative study was performed between IBS and NIBS design. The comparison was used to identify expected values of IBS cost savings with respect to cost premiums.

3.3. Data Collection

Data was collected from the U.S. Army Medical Command's Facility Management Support Operations Center (FMSOC) in June of 2012. The data points selected represent expenditures on scheduled and unscheduled maintenance for costs in dollars and actual hours. Scheduled and unscheduled maintenance in U.S. Army hospitals are performed to keep the facility in "good working order" and include "regularly scheduled adjustments and inspections, preventive maintenance tasks, and emergency response and service calls for minor repairs" (DoD 2010). The data source used in this study was the Defense Medical Logistics Standard Support (DMLSS).

3.3.1. Databases: Defense Medical Logistics Standard Support (DMLSS) and Joint Medical Asset Repository (JMAR)

FMSOC uses two primary databases for oversight and management: DMLSS and the Joint Medical Asset Repository (JMAR). The DoD's Military Health System (MHS) utilizes a database called the Defense Medical Logistics Standard Support (DMLSS) with a Facility Management (FM) module. DMLSS is accessible at U.S. Army hospitals or through connecting directly to the internet server at the location of the U.S. Army hospitals. DMLSS also links to a web-based database called the Joint Medical Asset Repository (JMAR). JMAR is accessible through approval of a system access request

(SAR). The data entry point is conducted at the DMLSS interface at the local U.S. Army hospitals. The JMAR performs synchronization with the DMLSS data and unfortunately does not always have the most up to date information.

These databases have the ability to capture facility costs. However, it appears that O&M data is the primary data captured at the facility level (Roy Hirchak, personal communication, June 25, 2012). Additionally, this database is likely to have hard indicators of information more than it is likely to have soft indicators. The difference is discussed with the primary reason being "the specificity of their applications" where the soft indicators "are sensitive to changes occurring in the cultural and organizational domains" (Pati et al. 2010). As of the date of the data pull, DMLSS was known to have more accurate data than JMAR. Despite that JMAR is easier to access than DMLSS, a data pull directly from DMLSS was conducted due to data reliability.

3.3.2. Data Screening

A query of costs in dollars and actual hours spent on scheduled and unscheduled maintenance for twelve U.S. Army hospitals from fiscal year (FY) 1997 to 2012 resulted in a data set of over ten thousand points representing twenty different building systems. Three U.S. Army hospitals utilized an IBS design and nine did not. The U.S. Army hospital size ranged from above 313k sf to over 1.9M sf (gross). Five U.S. Army hospitals are named Army Community Hospitals (ACH) and seven are named Army Medical Center's (AMC). The U.S. Army hospitals age between FY 1997-2012 varied from 1 to 63 years.

The data were screened to minimize error of the analysis. Successive screening began with facility selection, followed by time selection in fiscal year, then by relevant building system, and lastly for empty data elements (Table 1, Figure 8).

Table 1. Summary of Records Removed as a Result of Screening

Screening Criteria	Number of Records Prior to Screening	Number of Records Removed	Remaining Number of Records
Initial Data Set	10,298		
Comparable Facilities		7,668	
Fiscal Year		244	1373
Relevant Building Systems		910	
Empty Data Sets		103	

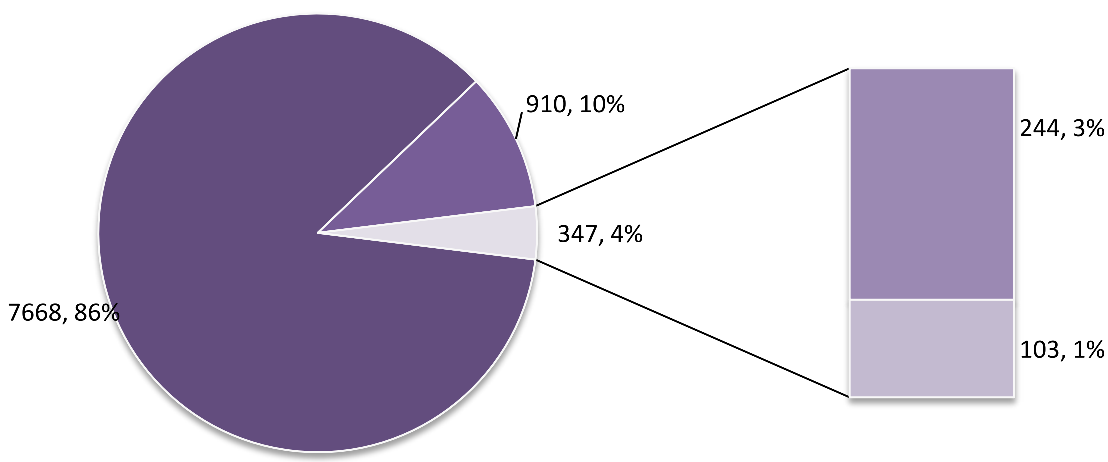


Figure 8. Number and Associated Percent of Records Removed from Screening

3.3.2.1. Screening for Comparable Facilities

The hospitals under responsibility, or command and control, of the U.S. Army Medical Department (AMEDD) were screened for comparable facilities (Table 2).

Table 2. U.S. Army Hospitals (AMEDD 2011)

Region	Installation	Name
Europe	Vilseck, Germany	Bavaria Medical Department Activity
Europe	Heidelberg, Germany	Heidelberg Medical Department Activity
Europe	Landstuhl, Germany	Landstuhl Regional Medical Center
Northern	Fort Drum, NY	Guthrie Medical Department Activity
Northern	Fort Knox, KY	Ireland Army Community Hospital
Northern	West Point, NY	Keller Army Community Hospital
Northern	Fort Lee, VA	Kenner Army Health Clinic
Northern	Fort Meade, MD	Kimbrough Ambulatory Care Center
Northern	Fort Eustis, VA	McDonald Army Community Hospital
Northern	Fort Bragg, NC	Womack Army Medical Center
Pacific	Camp Zama, Japan	Camp Zama
Pacific	Seoul, Korea	MEDDAC-Korea
Pacific	Honolulu, HI	Tripler Army Medical Center
Southern	Fort Polk, LA	Bayne Jones Army Community Hospital
Southern	Fort Campbell, KY	Blanchfield Army Community Hospital
Southern	Fort Sam Houston, TX	Brooke Army Medical Center, *changes in joint basing result in name changes from BAMC to the San Antonio Military Medical Center (SAMMC)*
Southern	Fort Hood, TX	Carl R. Darnall Army Medical Center
Southern	Fort Gordon, GA	Dwight D. Eisenhower AMC
Southern	Redstone Arsenal, AL	Fox Army Health Center
Southern	Fort Rucker, AL	Lyster Army Health Clinic
Southern	Fort Benning, GA	Martin Army Community Hospital
Southern	Fort Jackson, SC	Moncrief Army Community Hospital
Southern	Fort Sill, OK	Reynolds Army Community Hospital

Table 2 Continued		
Region	Installation	Name
Southern	Fort Stewart, GA	Winn Army Community Hospital
Western	Fort Wainwright, AK	Bassett Army Community Hospital
Western	Fort Huachuca, AZ	Bliss Army Health Center
Western	Fort Carson, CO	Evans Army Community Hospital
Western	Fort Leonard Wood, MO	General Leonard Wood Army Community Hospital
Western	Fort Riley, KS	Irwin Army Community Hospital
Western	Joint Base Lewis-McChord, WA	Madigan Army Medical Center
Western	Fort Leavenworth, KS	Munson Army Health Center
Western	Fort Irwin, CA	Weed Army Community Hospital
Western	Fort Bliss, TX	William Beaumont Army Medical Center

Of these, twelve U.S. Army hospitals were initially identified and selected as comparable for analyzing differences between healthcare facilities that integrate IBS design and healthcare facilities that do not (Roy Hirchak, personal communication, June 25, 2012). Although the number of patient beds in a health care facility is sometimes used as a metric for comparison, U.S. Army hospitals facility maintenance personnel generally use gross square feet as a metric for planning and comparing.

However, the two older U.S. Army hospitals are located outside of the continental United States (OCONUS), both are comprised of more than one main building, and both underwent significant renovation or renewal since initial construction. As a result of these factors, the two OCONUS facilities were not considered comparable and were excluded from further analysis.

Photos of the selected facilities are compiled in Appendix A. Data correction was performed to normalize differences due to location, facility size, and escalation.

3.3.2.2. Screening for Fiscal Year

The DMLSS database FM module was fielded and integrated starting in 1997; therefore, the data acquired were limited to dates after this year. Although initial query included some data from FY 2012, these were excluded to ensure fiscal years were represented by a full year of data. In removing FY 2012, 244 records of 2630 records were removed.

3.3.2.3. Screening for Relevant Building Systems

The DMLSS database records some twenty different building systems. As not every building system listed might be directly impacted by a design including interstitial spaces, it is important to consider how the data from one building system could affect the overall analysis. For example, over 165k hours at a cost of over $3.9M of maintenance for the building system roads and grounds would significantly skew a data collection of over 905k hours at a cost of over $35M for all building systems.

This study seeks to focus on building systems that are likely to be impacted by a design integrating IBS into the hospital. Other building systems were not anticipated to be directly impacted by design options of integrating IBS and were eliminated from this analysis. In removing these building systems, 910 records of 2386 records were removed (Table 3, Figure 9).

Table 3. Building Systems Screened

	Building System	Impact from IBS Design	Number of Records Removed
1	Alarm, Security and Building Management System	Anticipated	
2	Communications System	Anticipated	
3	Conveying System	Not Anticipated	164
4	Electrical Power & Distribution	Anticipated	
5	Electrical System	Anticipated	
6	Emergency Power & Lighting	Anticipated	
7	Exterior Closure	Not Anticipated	147
8	Fire Protection System	Anticipated	
9	Food Services Equipment	Not Anticipated	180
10	Heating, Ventilation & Air Conditioning	Anticipated	
11	Interior Construction	Anticipated	
12	Interior Finishes	Anticipated	
13	Plumbing	Anticipated	
14	Roads & Grounds	Not Anticipated	104
15	Roofing	Not Anticipated	40
16	Site Civil / Mechanical Utilities	Not Anticipated	33
17	Site Electrical Utilities	Not Anticipated	65
18	Special Construction Equipment	Not Anticipated	120
19	Substructure	Not Anticipated	24
20	Superstructure	Not Anticipated	33

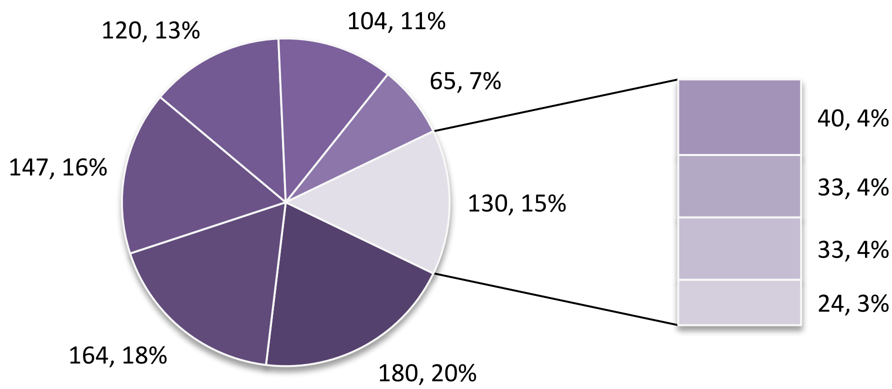


Figure 9. Number and Associated Percent of Records Removed from Screening of Relevant Building Systems

Primarily, the building systems anticipated to be directly impacted by a design integrating IBS into the U.S. Army hospitals would include HVAC, electrical, plumbing, and interior works maintenance data. For categorization purposes the following building systems were combined into electrical: Alarm, Security and Building Management System; Communications System; Electrical Power & Distribution; Electrical System; and Emergency Power & Lighting. The following building systems were combined into plumbing: Fire Protection System; Plumbing. The following building systems were combined into interior works: Interior Construction; Interior Finishes (Table 4).

Table 4. Building Categories

Building Category	Building Systems Included
HVAC	Heating, Ventilation & Air Conditioning
Electrical	Alarm, Security and Building Management System; Communications System; Electrical Power & Distribution; Electrical System; and Emergency Power & Lighting
Plumbing	Plumbing; Fire Protection System
Interior Works	Interior Construction; Interior Finishes

3.3.2.4. Screening for Empty Data Elements

For this analysis, it is assumed that if no time is spent and no cost is incurred, then maintenance was not performed. Entries with 0.00 hours or no entry listed for hours and 0.00 total cost were removed. 88 records with 0.00 dollars total cost spent of 1373 records had at least some fraction of hours attributed to the maintenance, and thus remained in the set of data to be analyzed although the rationale for entry of 0.00 dollars in total cost is not certain. It is not known whether the empty data sets were input manually, or if it was a DMLSS system error.

3.3.3. Data Characteristics

The remaining data set of 1373 records represents ten U.S. Army hospitals, three of which include an IBS design (Table 5, Figure 10).

Table 5. Data Characteristics

Installation	Name	# of Records	Primary Qty in SF	Facility Built Date
FORT BRAGG _ NC	Womack	129	1,947,453	1998
FORT SAM HOUSTON _ TX	BAMC/SAMMC	195	1,350,734	1996
FORT BLISS _ TX	Wm Beaumont	74	668,377	1972
FORT GORDON _ GA	Eisenhower	168	622,700	1974
FORT HOOD _TX	Darnall	157	590,202	1966
FORT SILL _ OK	Reynolds	122	543,023	1994
FORT CARSON _ CO	Evans	159	515,920	1986
FORT CAMPBELL _ TN	Blanchfield	170	494,420	1982
FORT STEWART _ GA	Winn	167	334,072	1983
FT. WAINWRIGHT _ AK	Bassett	32	313,202	2007

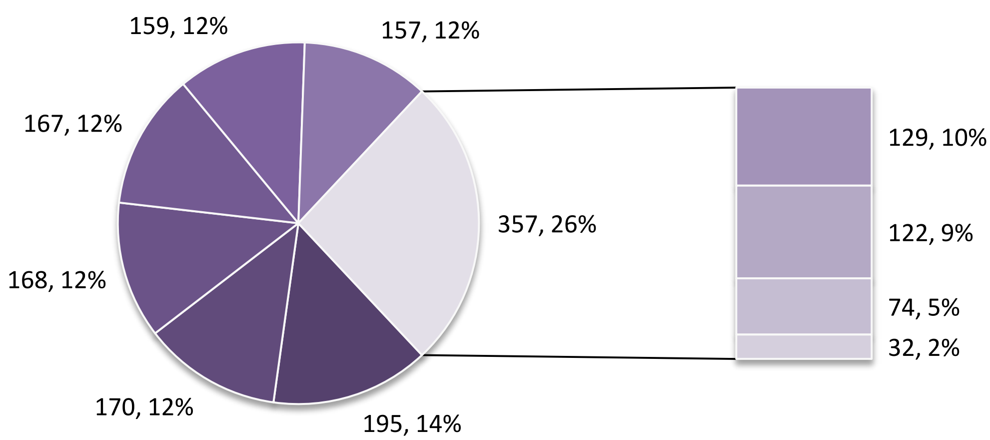


Figure 10. Number and Associated Percent of Records for each MTF Remaining After Applying Screening Criteria

Womack Army Medical Center on Fort Bragg, Reynolds Army Community Hospital on Fort Sill, and BAMC/SAMMC on Fort Sam Houston are the three U.S. Army hospitals in this study which have IBS deign integrated into the facility.

3.3.4. Data Correction

Data correction was required for facility location, cost comparison at net present value, and facility size.

3.3.4.1. Area Cost Factor

City Cost Indexes (CCI) are available in R.S. Means as "a percentage ratio of a specific city's cost to the national average cost of the same item at a stated time period" published each year representing material, installation, labor, and equipment rental costs (RSMeans 2012). Generally, the closest listed city would be used in applying the location factor, or area cost factor (ACF). However, RSMeans does not list military installations. For the specific case of the U.S. Army hospitals, FY12 Unabridged Area Cost Factors were obtained from the DoD Facilities Pricing Guide (Table 6), which are publicly available from the Whole Building Design Guide (WBDG 2012). The ACFs were applied to the data using the following formula:

$$Normalized\ Cost\ =\ Location\ Specific\ Cost\ *\ Area\ Cost\ Factor$$

The ACF was applied only to costs in dollars spent but not the time in actual hours spent.

Table 6. Area Cost Factors (WBDG 2012)

State Average	ACF	Selected Area	ACF
Alaska Average	1.77	Fairbanks	1.89
		Fort Wainwright	1.89
Colorado Average	1.04	Colorado Springs	1.07
		Fort Carson	1.07
Georgia Average	0.84	Atlanta	0.87
		Fort Gordon	0.92
		Fort Stewart	0.83
Hawaii Average	2.16	Honolulu	2.10
		Fort Shafter	2.11
		Tripler Army Medical Center	2.11
Kentucky Average	0.94	Louisville	0.98
		Fort Campbell	1.01
North Carolina Average	0.84	Fayetteville	0.86
		Joint Base Pope-Bragg	0.90
Oklahoma Average	0.90	Lawton	0.90
		Fort Sill	0.90
Texas Average	0.81	San Antonio	0.83
		Dallas	0.86
		Fort Bliss	0.96
		Fort Hood	0.82
		Fort Sam Houston	0.85
Germany Average	1.20	Frankfurt	1.24
		Kaiserslautern	1.19

3.3.4.2. Net Present Value (NPV) Factor

The DoD Facilities Pricing Guide listed escalation rates only from 2003 (historical) to 2017 (projected). However, the range of data was from FY 1997 to FY 2011. Therefore, RSMeans historical cost indexes were used to normalize cost data for each original fiscal year and applied to adjust the data to the NPV in 2012 using the following formula:

$$Normalized\ Cost = Cost_{Original\ Year} \times \frac{Index\ for\ Year\ 2012}{Index\ for\ Year_{Original\ Year}}$$

3.3.4.3. Size Factor

A correction for size in square feet was applied to both costs in dollars and actual hours spent on scheduled and unscheduled maintenance.

$$Unit\ Cost\ = \frac{Cost}{Facility\ Size}$$

$$Unit\ Time\ = \frac{Actual\ Hours\ Spent}{Facility\ Size}$$

Correction for size in both unit costs and unit time spent allows a comparison per square feet. Adjusted unit costs incorporated each of the correction factors and unit time incorporated the size factor to normalize the data.

3.3. Data Analysis

Descriptive statistics were performed for different data combinations: all screened data points, all data points from a U.S. Army hospital with IBS design, all data points from a U.S. Army hospital without IBS design. The data from unscheduled and scheduled maintenance were further separated into each of the four building system categories.

The student's T-test was performed for data from U.S. Army hospitals with IBS design (referred to as 'IBS') and for data U.S. Army hospitals without IBS design, or conventional non-interstitial building system design ('NIBS'). Although acronyms for IBS and NIBS can vary based upon the topic, IBS is a standard acronym used in the Unified Facility Criteria (UFCs) and NIBS is used for similarity of naming convention between the two types of building design. The data from the IBS and NIBS was further analyzed for data from unscheduled maintenance and data from scheduled maintenance.

Scatter plots and histograms were created for each building system, and scheduled and unscheduled maintenance for comparison between IBS and NIBS.

IBS and NIBS data was plotted across fiscal year (FY) and age of the facility for scheduled and unscheduled maintenance in each of the building system categories. The yearly averages were also plotted.

Histograms and the associated cumulative distribution were used to determine the range for probability and expected values of IBS and NIBS. The difference of expected values was then compared to expected values of cost premiums to determine the feasibility of integrating IBS design as a real option.

Decision analysis was used to compare potential savings with likely costs between IBS and NIBS in U.S. Army hospitals.

4. FINDINGS

4.1. Introduction

1373 records were analyzed representing a sum of over 500,000 actual hours of maintenance spent for a total cost of almost $18.6 million over a 15-year timeframe (FY 1997 – FY 2011) of ten U.S. Army hospitals. The net present value (NPV) in 2012 and adjusted for location represents a total cost of over $21.8 million.

4.2. Building System Summary

For the four selected building systems, electrical maintenance was performed most often but HVAC maintenance required the most expenditure in terms of cost and time.

The number of records entered into DMLSS from FY 1997-2011 was largest in electrical, followed by plumbing (Figure 11). The numbers of HVAC and interior records entered into DMLSS were almost the same. Each adjusted unit cost ($/sf) was represented by a unit time (hr/sf) of at least 0.15 hrs/sf that was performed.

The percent of dollars and hours expended on average adjusted unit cost of facility maintenance was largest for HVAC, followed by interior. Plumbing and electrical cost least and took the least average unit time to perform (Figure 12).

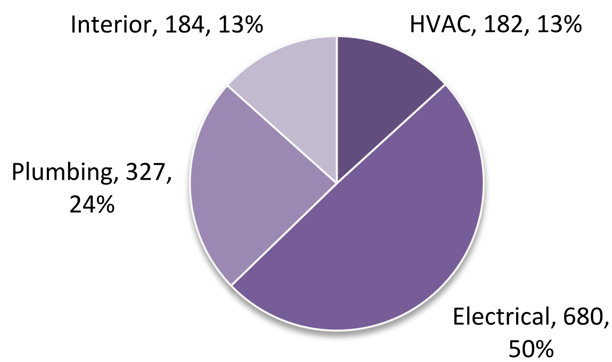


Figure 11. Number of Records Entered into DMLSS from FY 1997-2011 by Building System

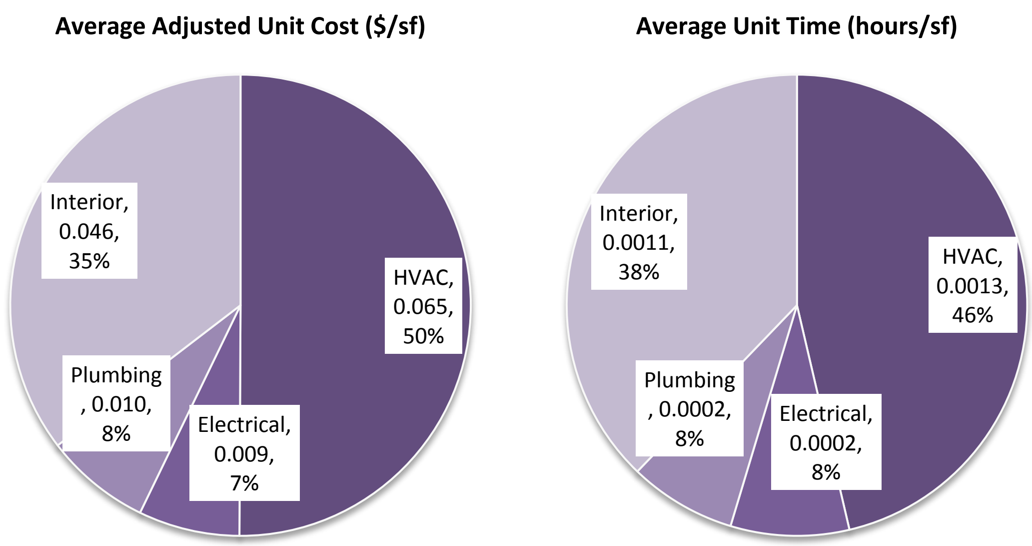


Figure 12. Percent of Building System Average Values

4.2.1. Hypothesis Testing Results

Descriptive statistics confirmed a significant difference between IBS and NIBS design in all four building systems facility maintenance for most cases. The data set was stratified by the four selected building systems. IBS and NIBS U.S. Army hospitals were compared through the use of a student's T-test to test the following hypotheses for both costs and time spent on facility maintenance:

$$H_{0_n}: \mu_{IBS} = \mu_{NIBS}$$

$$H_{a_n}: \mu_{IBS} < \mu_{NIBS}$$

Data was not found to test the hypothesis in this study with respect to the question: Is there any difference in quality due to disruptions of care provided between a hospital that has interstitial building spaces and a hospital without interstitial building spaces?

The results of the Student T-test are provided (Table 7).

Table 7. Results of Student T-test

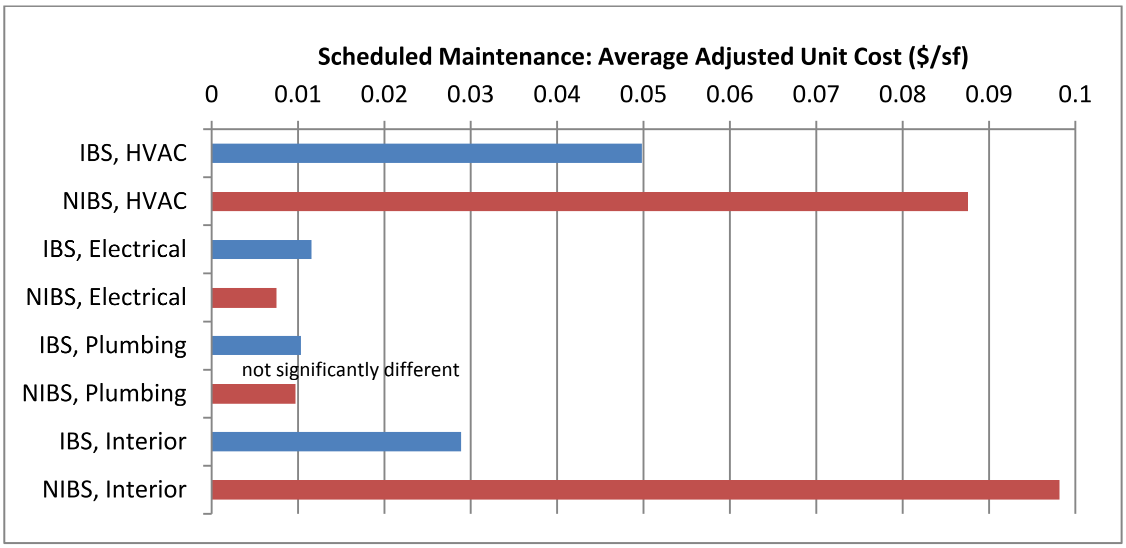
	Quality	Cost	Time
Null Hypothesis	$H_{0_1}: \mu_{IBS} = \mu_{NIBS}$	$H_{0_2}: \mu_{IBS} = \mu_{NIBS}$	$H_{0_3}: \mu_{IBS} = \mu_{NIBS}$
Alternate Hypothesis	$H_{a_1}: \mu_{IBS} < \mu_{NIBS}$	$H_{a_2}: \mu_{IBS} < \mu_{NIBS}$	$H_{a_3}: \mu_{IBS} < \mu_{NIBS}$
Result	Not Evaluated	Reject H_{0_2}	Reject H_{0_3}

4.2.2. Costs

With scheduled maintenance, NIBS was more costly than IBS for the HVAC and interior building systems. There was not a significant difference for plumbing. Although electrical was significantly different, with a higher average value for IBS, this value was far smaller than HVAC or interior.

For unscheduled maintenance, NIBS was significantly different and was found as a higher average adjusted unit cost than IBS for every building system considered.

Figure 13 shows the differences in average adjusted unit costs between IBS and NIBS.



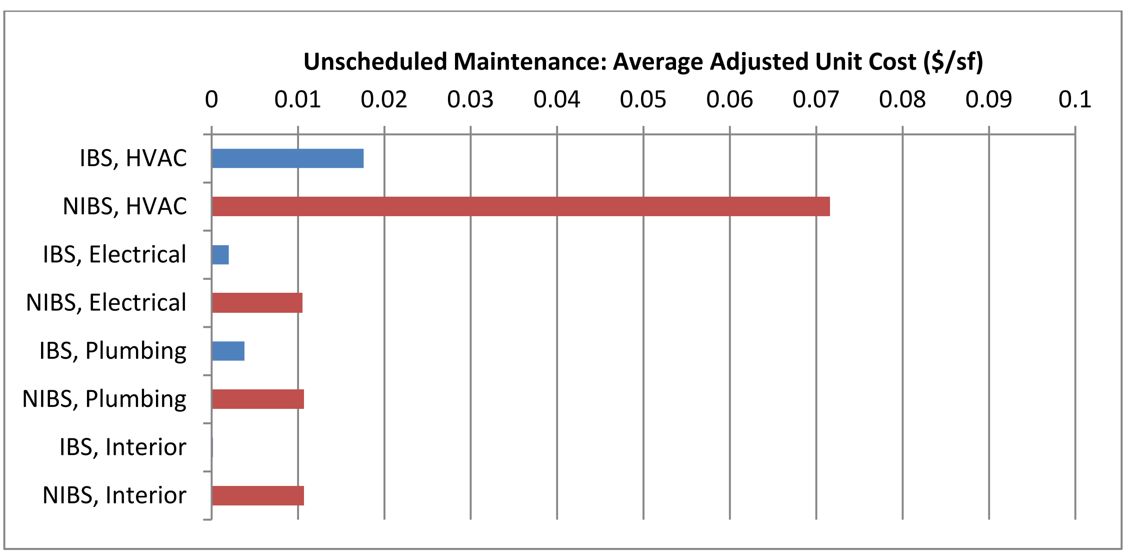


Figure 13. Comparison between IBS and NIBS of Scheduled and Unscheduled Maintenance for Average Adjusted Unit Cost ($/sf)

4.2.3. Time

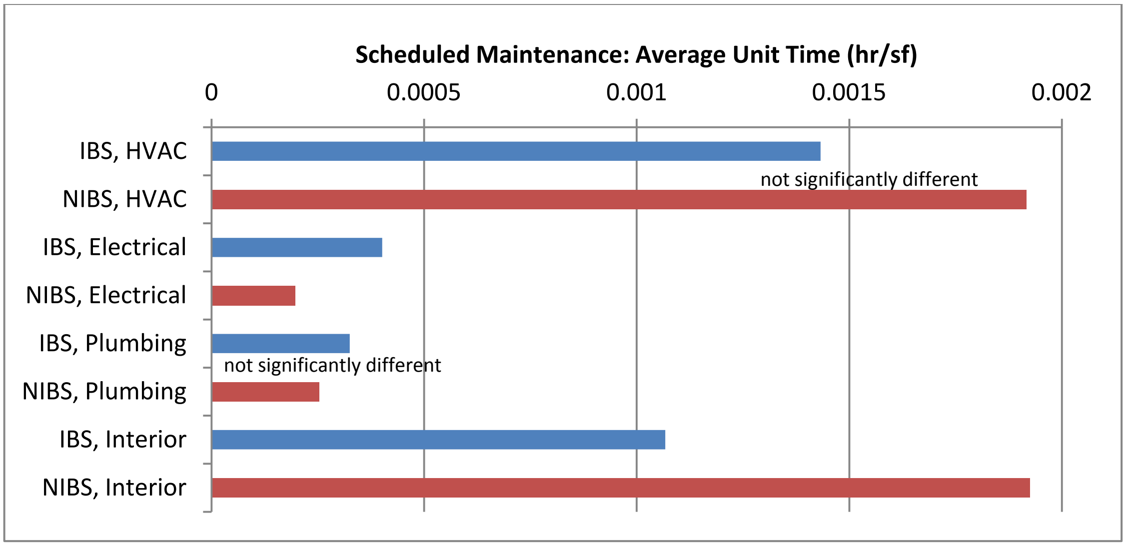
There were similar findings for the expenditures of time in the data collected from DMLSS.

Regarding scheduled maintenance, more time was spent on NIBS than IBS for the HVAC and interior building systems, although HVAC was not significantly different between IBS and NIBS. Also, there was not a significant difference for plumbing. Although electrical was significantly different, with a higher average value for IBS, this value was far smaller than HVAC or interior.

For unscheduled maintenance, NIBS was significantly different and was found as a higher average unit time expended than IBS for every building system considered.

Figure 14 shows the differences in average adjusted unit costs between IBS and NIBS.

The findings of the summary and descriptive statistics of average values of the four building systems indicate a hospital with IBS design may provide cost savings.



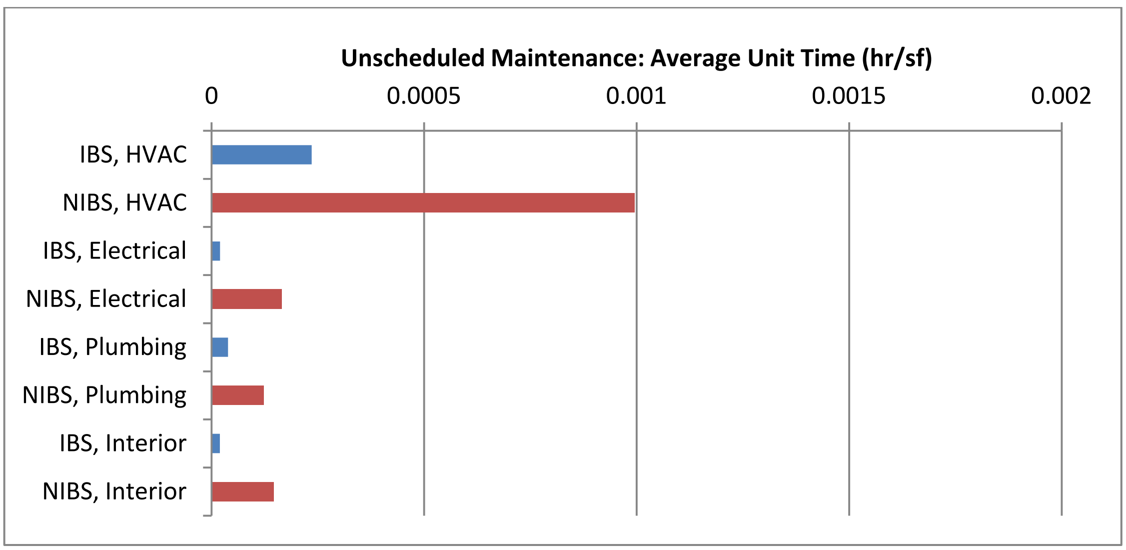


Figure 14. Comparison between IBS and NIBS of Scheduled and Unscheduled Maintenance for Average Unit Time (hr/sf)

4.3. Distribution of Maintenance over Fiscal Year

Distributions of maintenance over fiscal year were considered to identify potential trending or outliers. The data from each fiscal year was averaged for the total number of facilities that provided data to DMLSS for the respective fiscal year. A maximum of three IBS facilities and a maximum of seven NIBS facilities were included in each set, but not every facility always reported maintenance performed in each set. For example, for unscheduled HVAC in 2001 there were zero IBS facilities reporting maintenance performed but three NIBS facilities did report maintenance performed. For annual maintenance averages, blue diamonds (♦) represent data from IBS and red squares (■) represent data from NIBS. Scheduled maintenance is displayed on the left and unscheduled maintenance is displayed on the right.

4.3.1. Costs

Findings for the annual maintenance averages by building system of adjusted unit cost show a trend that NIBS is generally more expensive than IBS, with some exceptions (Figure 15). The exceptions are found mostly in scheduled maintenance. This could indicate that as IBS provides greater accessibility, there is greater encouragement for maintenance personnel to perform all scheduled maintenance.

The costs for scheduled maintenance are found to be higher than unscheduled maintenance for electrical and interior building systems, with NIBS generally more expensive than IBS (except in scheduled maintenance for electrical).

Even though the data was adjusted to NPV 2012, time does show a generally increasing trend for maintenance. The application of reliability centered maintenance may have the ability to help level off future increases. The possibility of this can be seen starting in FY 2009 in IBS (Scheduled HVAC), IBS (Scheduled Plumbing), NIBS (Scheduled Electrical), NIBS (Unscheduled HVAC), and NIBS (Unscheduled

Electrical). Additional data should be collected, or input retroactively into DMLSS, to possibly verify this finding.

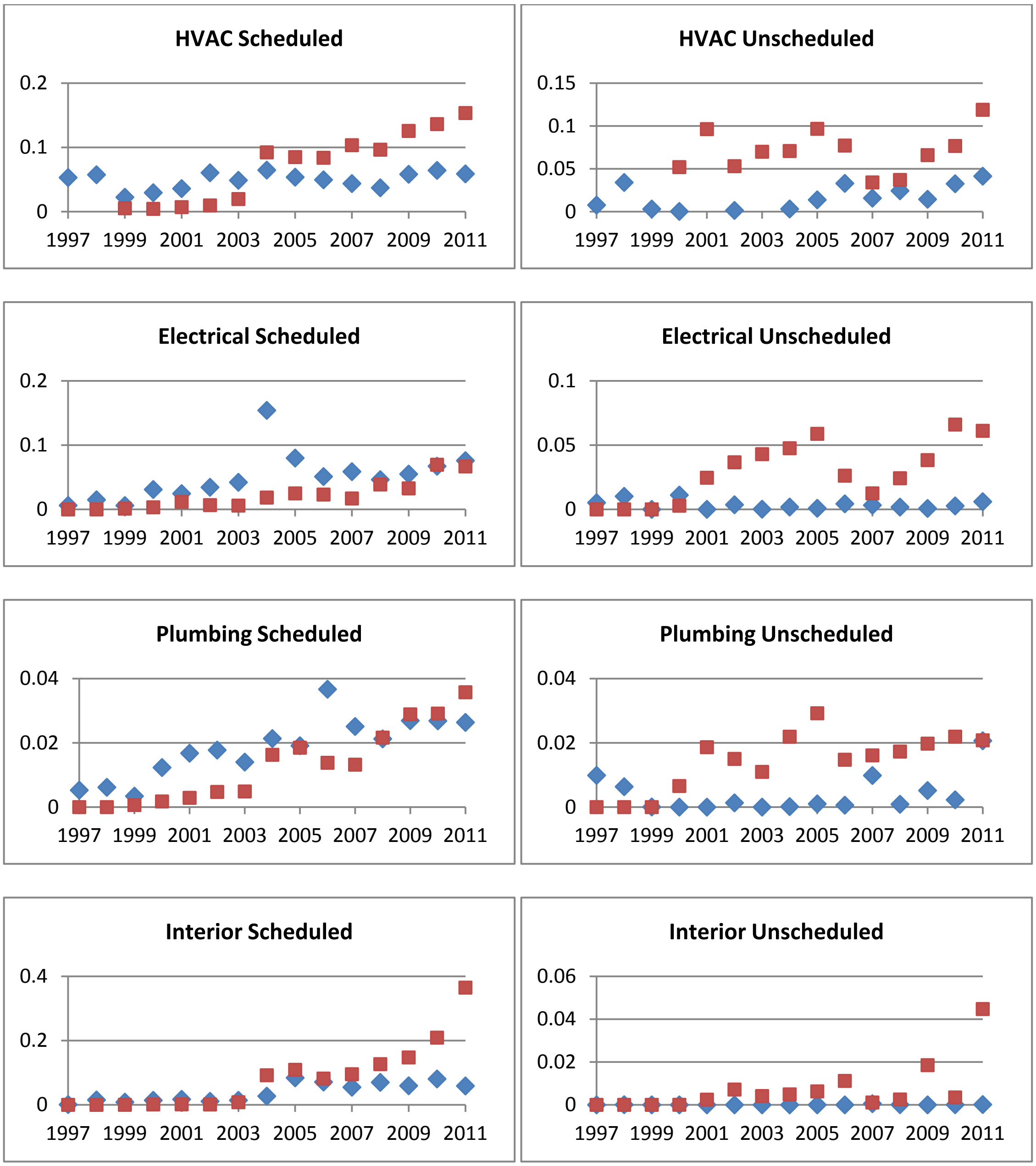


Figure 15. Plots of Average Adjusted Unit Costs ($/sf) Over Fiscal Year

4.3.2. Time

The findings for time are shown (Figure 16).

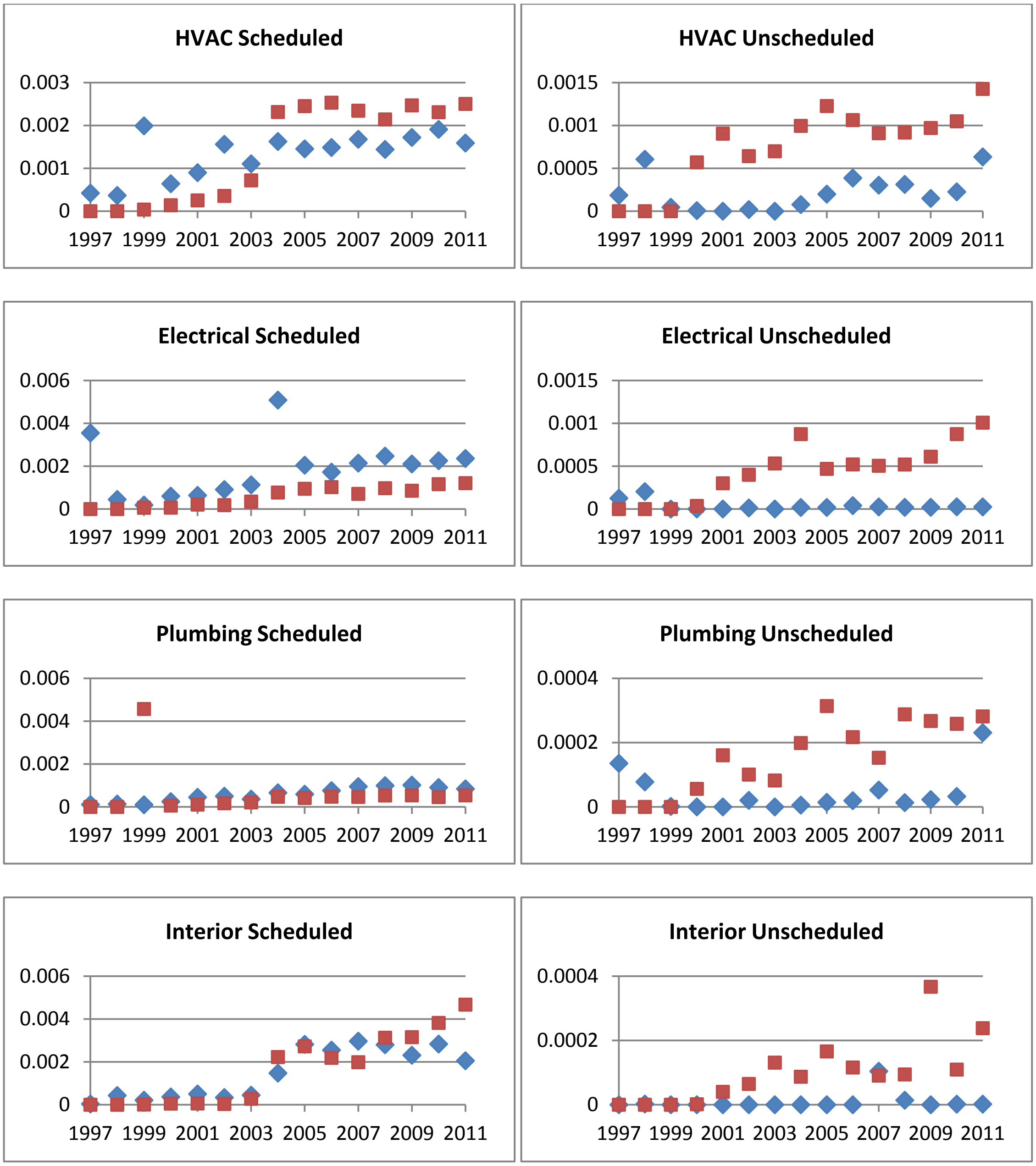


Figure 16. Plots of Average Unit Time (hr/sf) Over Fiscal Year

Findings for the annual maintenance averages by building system of unit time also show a trend that NIBS generally requires more time than IBS, with some exceptions (Figure 16).

As with the cost, the exceptions are also found in scheduled maintenance, and a similar rationale is assumed. Scheduled maintenance is found to take more time than unscheduled maintenance for each building system.

Differences in costs and time indicate variability induced by confounding factors. Outliers may be attributed to specific facilities, shown in Appendix B.

4.4. Distribution of Maintenance over Facility Age

Distributions of maintenance over facility age were considered to identify potential trending or outliers. Here, the data was averaged over the age of the facility with a maximum of three IBS facilities and a maximum of seven NIBS facilities. Again, data from DMLSS did have missing sets. For example, in unscheduled HVAC there were zero facilities that reported any maintenance performed at ages five years or seven years. Yet for age seventeen, one IBS facility and two NIBS facilities reported maintenance was performed. For annual maintenance averages, blue diamonds (♦) represent data from IBS and red squares (■) represent data from NIBS. Scheduled maintenance is displayed on the left and unscheduled maintenance is displayed on the right.

For both costs and time, limited sets of IBS and NIBS data are recorded at the same facility age. Despite this limitation, the distribution shows some areas of overlap.

Throughout the different scenarios of scheduled and unscheduled maintenance for the four different building systems, NIBS is generally found to vary greater in both costs and time than IBS. There are some trends of stability, which occurs in more scenarios for scheduled maintenance than for unscheduled maintenance, but not necessarily more for NIBS than for IBS.

The age of a facility is often believed to require maintenance following the "bathtub curve", although the fallacy to this reliability is identified (Smith and Hinchcliffe 2004). The data captured in this study is not found to follow a typical "bathtub curve".

4.4.1. Costs

The costs for the averages of annual maintenance over facility age have some years that both IBS and NIBS data is reported (Figure 17).

In scheduled maintenance, NIBS is found to be more expensive than IBS for ages zero through four, but less expensive in age sixteen and seventeen. Several reasons for this are possible, including adoption of RCM in recent years, changes in building systems technology, and limited data sets.

In unscheduled maintenance at age seventeen, NIBS is found to be more expensive than IBS in HVAC and electrical but not in plumbing. However, plumbing has greater variability than HVAC, electrical, and interior in unscheduled maintenance costs. Interior did not have an overlapping data set of IBS and NIBS for unscheduled maintenance costs.

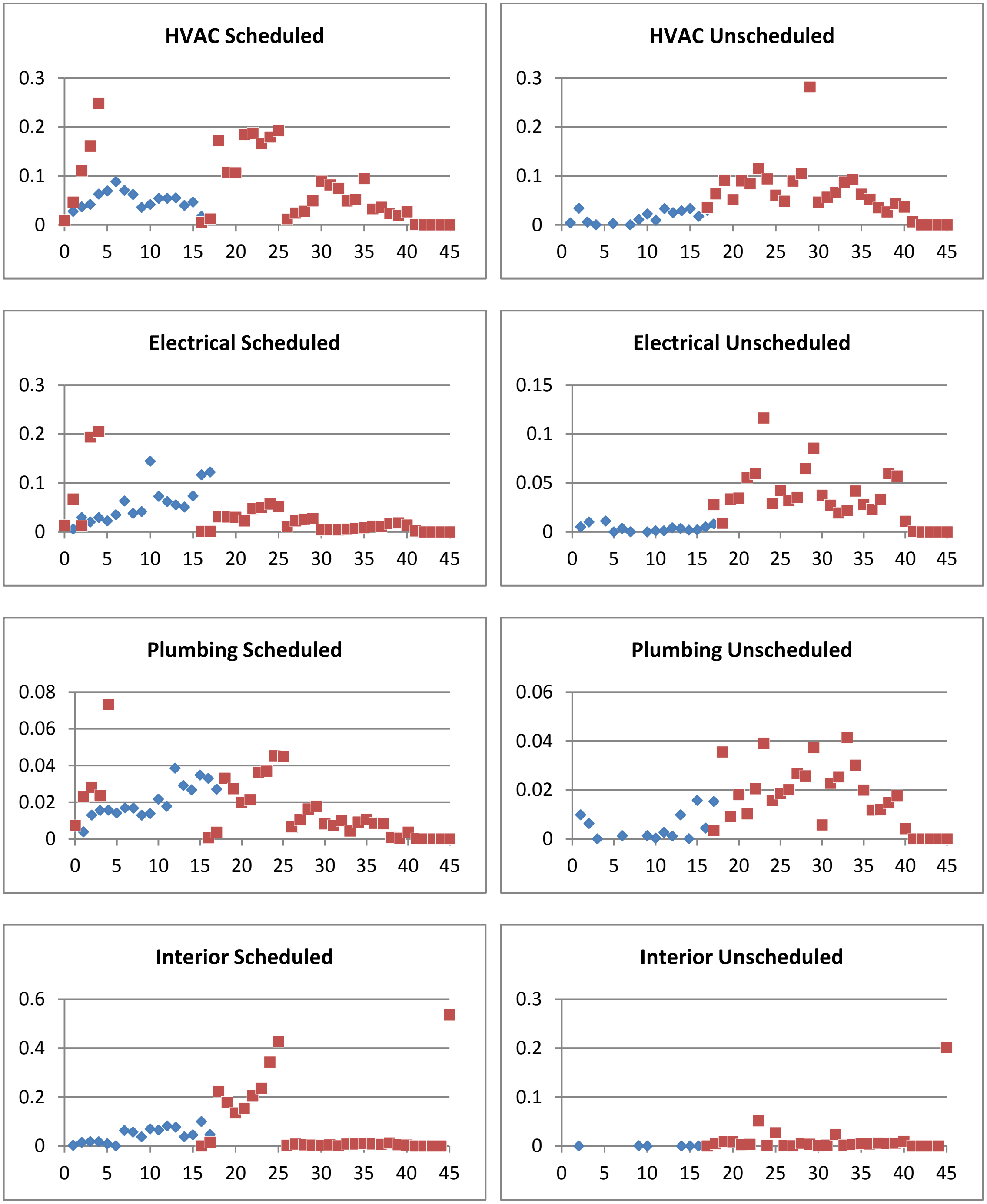


Figure 17. Plots of Average Adjusted Unit Costs ($/sf) Over Facility Age

Stability was found in some areas. Interior and electrical scheduled maintenance appeared more stable after 25 years of age, which included only NIBS data. One reason for this could be that if a major renovation was performed in recent years, the facility may have been modernized with building equipment that requires less scheduled maintenance. Another reason could be the application of RCM. IBS data should be monitored closely in the future to determine what ages stability is reached, and what are potential factors. IBS interior scheduled maintenance was most stable of the four building systems, but did show a slightly increasing trend.

For unscheduled maintenance, IBS demonstrated greater stability than NIBS for HVAC, electrical, and plumbing. Interior had the least variability across the 45 year lifespan. One reason for the greater variation found in plumbing here could be that the average value shown was affected by a facility that reported a much higher maintenance cost for a particular year. Other confounding factors could be attributed.

4.4.2. Time

Findings for the annual maintenance averages by building system of unit time have limited sets of overlapping IBS and NIBS data (Figure 18). The findings for time are generally correlated with the findings for costs with a few exceptions.

In scheduled maintenance ages zero to four, NIBS did not always take more time to perform maintenance than IBS. This finding indicates that with greater accessibility to work areas, maintenance personnel may be spending more time to perform the scheduled maintenance required in IBS facilities. If this is true, the alternate question arises: are maintenance personnel in NIBS facilities avoiding performing scheduled maintenance because it is too difficult to access?

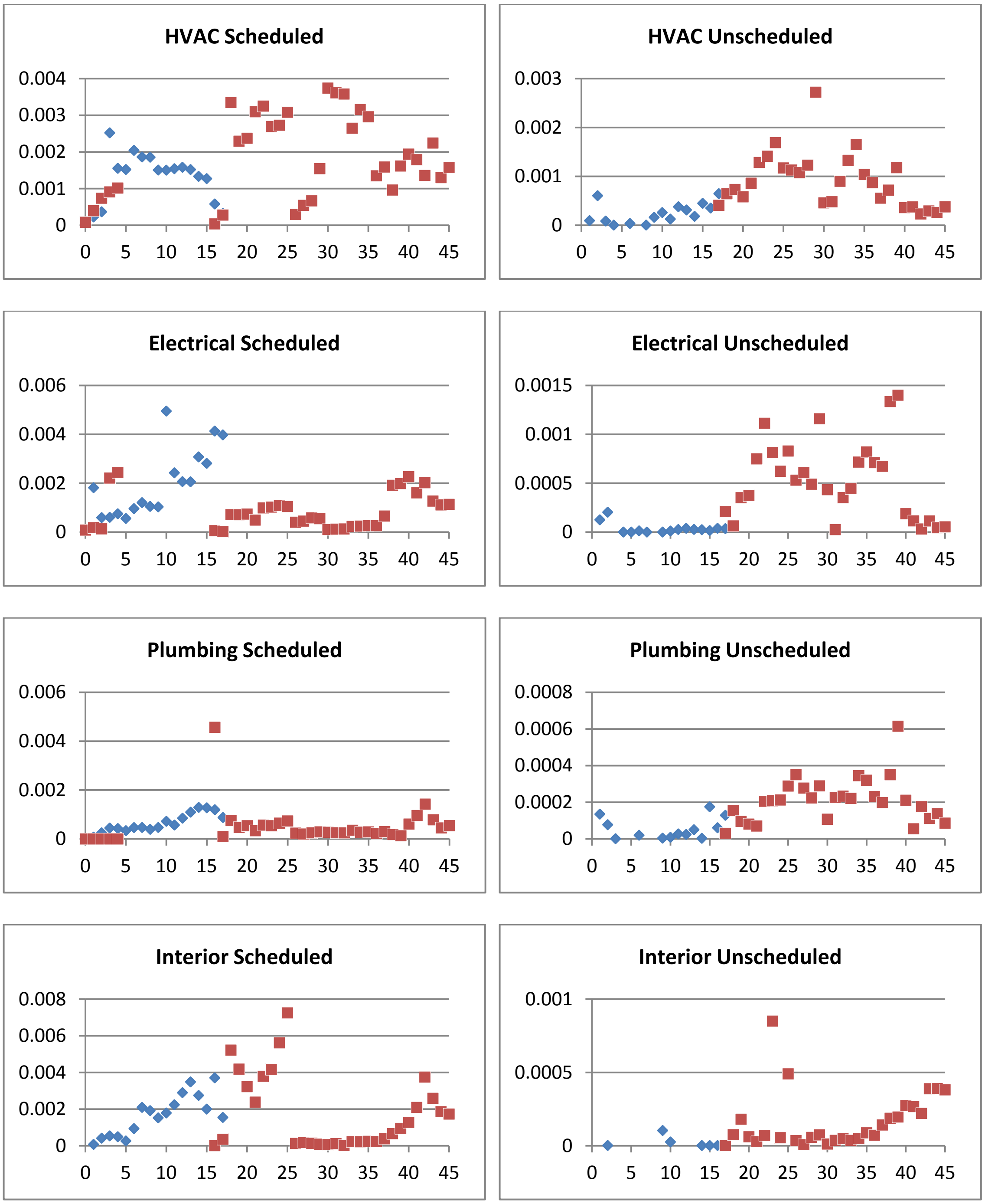


Figure 18. Plots of Average Unit Time (hr/sf) Over Facility Age

An AMEDD survey targeted towards maintenance workers could be issued to help answer this question.

In unscheduled maintenance, the difference between costs and time can be seen in HVAC. While costs were lower for IBS than NIBS, IBS took more time to perform the maintenance than NIBS. The rationale for accessibility is similar as described for scheduled maintenance.

4.5. Relationship Between Expenditures in Time and Money

The relationship between costs and time for facility maintenance include material costs and the time the maintenance worker spent on performing the maintenance. The correlation of expenditures for the amount of time with the amount of money are shown for scheduled and unscheduled maintenance for each building system. The values of the amount of time are in hours per square foot and the values of the amount of money are in dollars per square foot, corrected as previously described.

A linear relationship with a lower slope indicates material costs are not as high as compared to a higher slope or a nonlinear relationship such that the amount of money increases more sharply than the amount of time expended. Trendlines for linear regression are shown with slopes of IBS and NIBS, where the coefficient of determination, R^2, indicates the proportion of total variability, or significance of the linear relationship. Although R^2 near "1" is often considered a "good" model to fit the data, "good" is subject to interpretation and may be different based upon the nature of expected variability in different building systems. However, slopes of IBS and NIBS can be relatively compared for scheduled and unscheduled maintenance in the four different building systems.

4.5.1. Scheduled Maintenance

In scheduled maintenance, NIBS generally expends a greater amount of money for amount of time than does IBS (Figure 19).

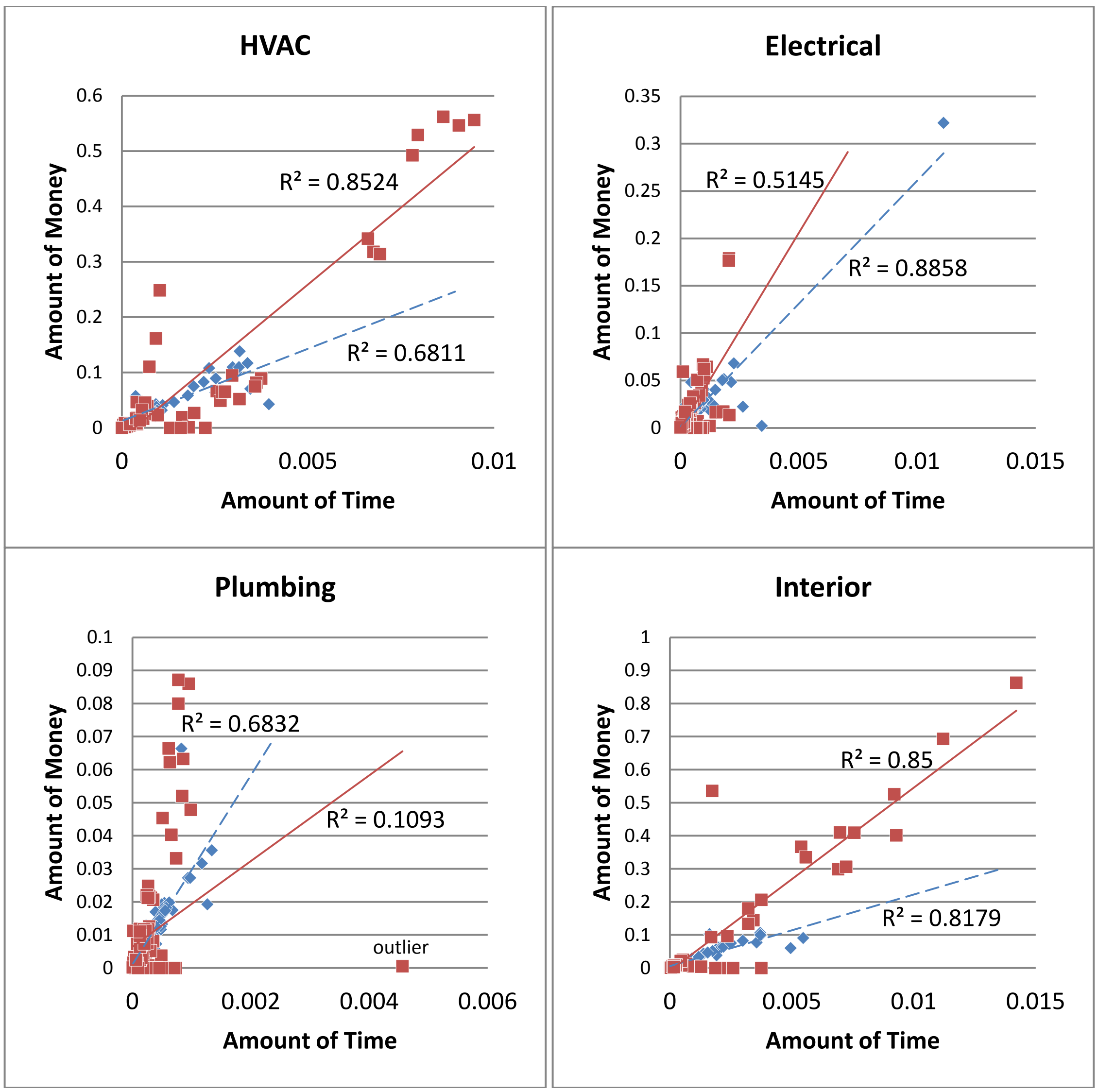


Figure 19. Relationships Between Amount of Time and Money Spent on IBS and NIBS U.S. Army Hospitals for Scheduled Maintenance

Although, the slopes of plumbing are the opposite, if the outlier of NIBS (amount of money = 0.00456, amount of time = 0.000535) were eliminated, then plumbing would also follow the trend of NIBS expending a greater amount of money for amount of time than IBS. Of the four building systems, plumbing costs the most for the amount of time performing the scheduled maintenance. One reason for this could be higher levels of material costs, such as costs for copper. The red solid line shows the slope of NIBS and the blue dashed line shows the slope of IBS.

4.5.2. Unscheduled Maintenance

In unscheduled maintenance, NIBS still expends a greater amount of money for amount of time than does IBS although slopes of IBS and NIBS are closer than what is found with scheduled maintenance (Figure 20). There is greater variability in the data for unscheduled maintenance than there is for scheduled maintenance.

Eliminating outliers in NIBS electrical data would lower the slope but IBS electrical data has greater variation and thus the slope might be increased or decreased, depending upon which outliers were removed. Similarly, eliminating outliers in NIBS interior data would lower the slope. However, for NIBS plumbing, variability is too great and thus slope might be increased or decreased, depending upon which outliers were removed. Additional data should be collected on IBS to better understand the correlation between expenditures of time and money.

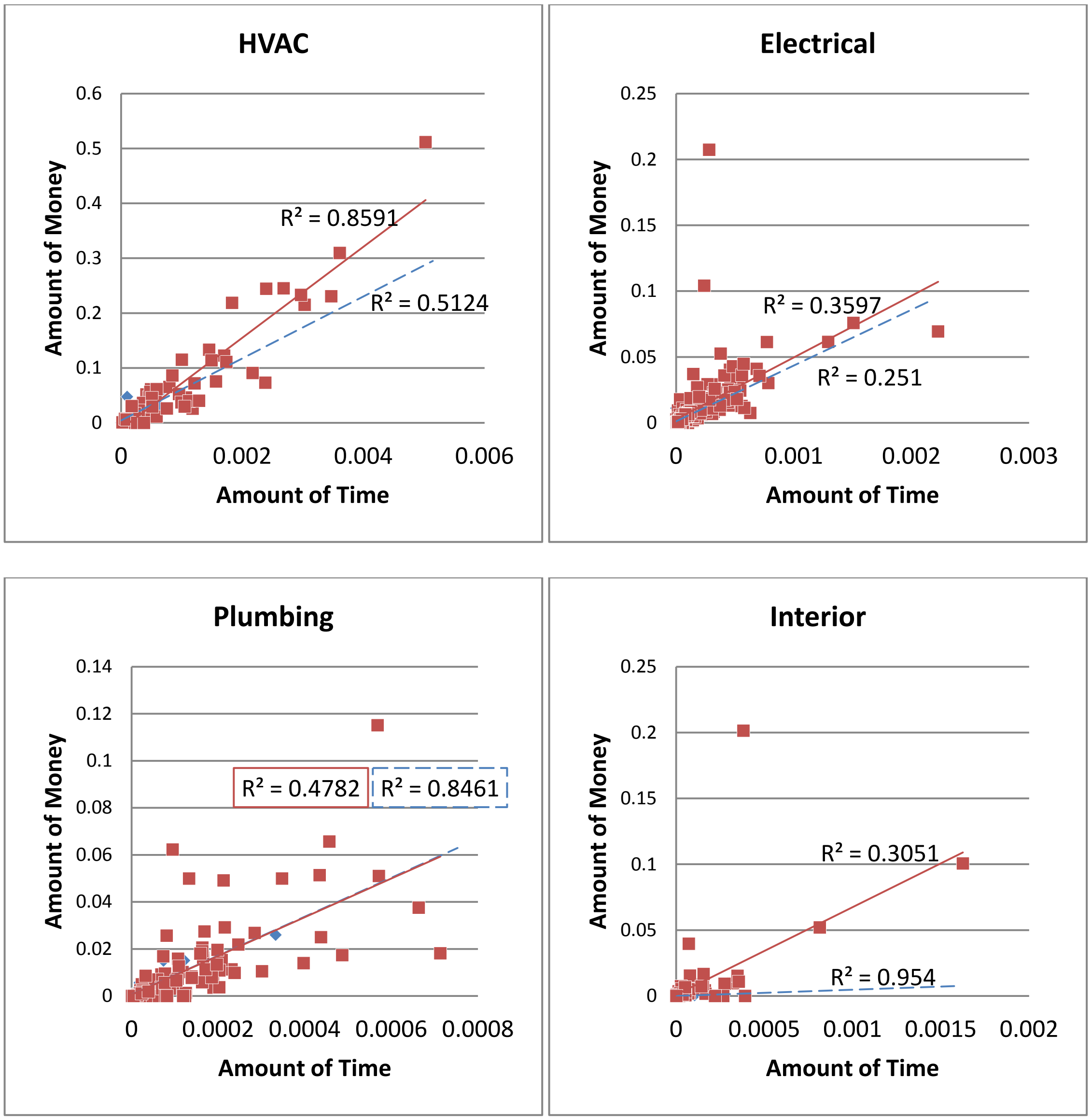


Figure 20. Relationships Between Amount of Time and Money Spent on IBS and NIBS U.S. Army Hospitals for Unscheduled Maintenance

Imperfect correlations between time and money can be attributed to a variety of confounding factors, of which one is the cost of materials used in performing the maintenance. However, no negative correlations were observed, and it can be said there is a general correlation that as time is spent on maintenance there is a cost associated with the facility maintenance.

Despite variability and model fit challenges, the scale of the y-axis, ‘Amount of Money’ and the scale of the x-axis ‘Amount of Time’ are much lower for IBS than NIBS for both scheduled and unscheduled maintenance. One of the reasons for this could be that because IBS offers greater accessibility, fewer resources (such as materials required to perform the maintenance) are required to perform the associated maintenance in the same time frame than what is required for NIBS. If this was the case, then a lower cost would be expected for IBS maintenance than NIBS maintenance.

4.6. Histograms of Maintenance Costs

The data reported in DMLSS was distributed into histogram bins of $0.01 per square foot measuring the frequency at which each facility performed maintenance. IBS facilities are shown in blue and NIBS facilities are shown in red (Figure 21).

The histograms show the variance occurring in the IBS and NIBS data. Scheduled maintenance showed greater variance across the bins for both IBS and NIBS than did unscheduled maintenance. Unscheduled maintenance had greater variance for NIBS while IBS was more concentrated in lower costing bins.

The histograms show NIBS more frequently requires more expensive maintenance than does IBS for unscheduled maintenance in all four building systems.

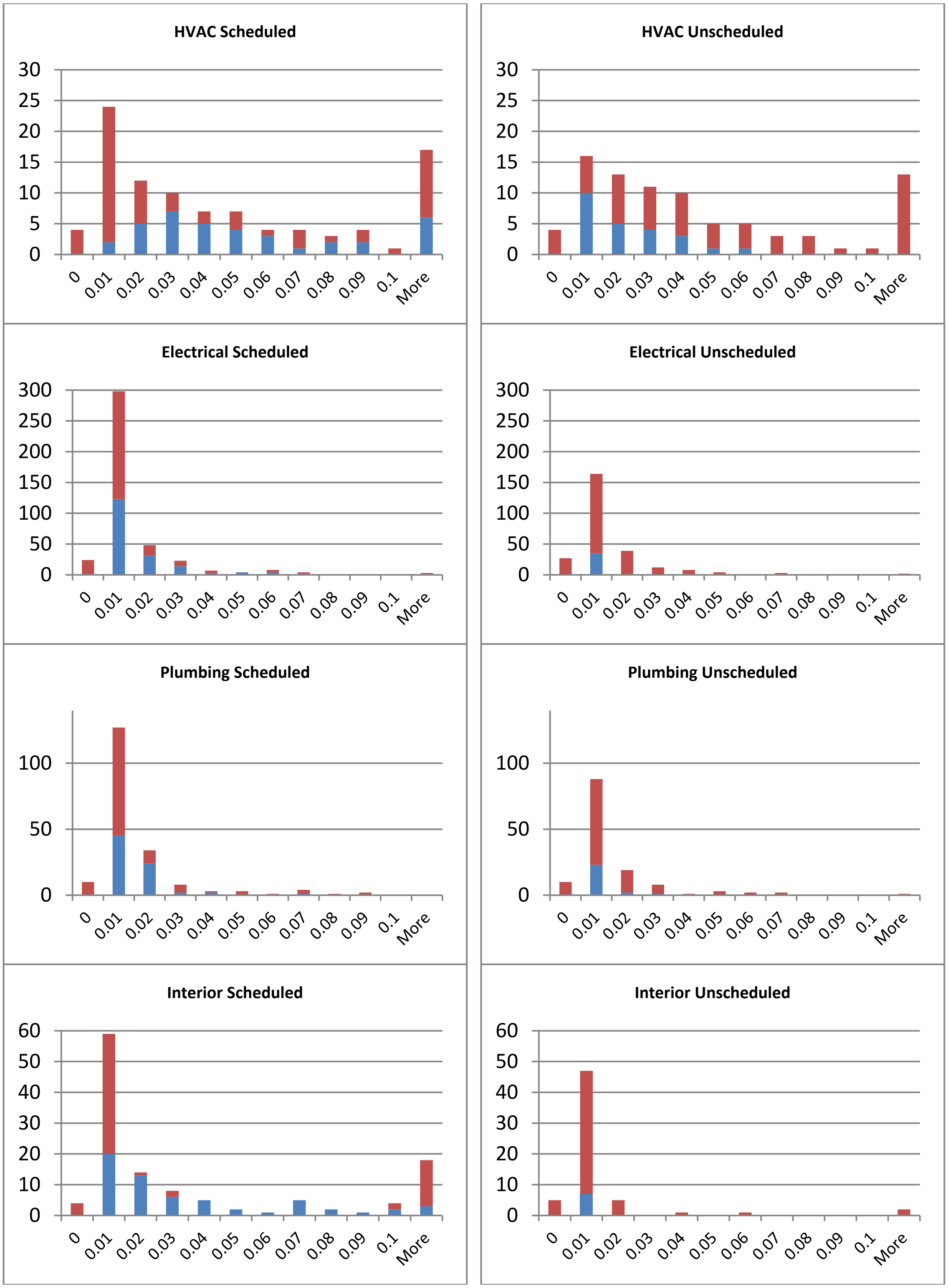


Figure 21. Distribution of Adjusted Unit Costs ($/sf) of Scheduled and Unscheduled Maintenance for IBS and NIBS

4.7. Decision Analysis

4.7.1. Decision Tree Analysis

Of the different decision analysis tools available, a decision tree analysis (DTA) was used to compare potential savings with likely costs between IBS and NIBS. DTA uses expected values to find the best alternative. For each scenario, the end node or outcome is associated with a probability of occurrence and the chance node represents the sum of those values at their respective probability. The probabilities in each branch always sum to equal 1. That is, the sum of the probabilities of occurrence of each outcome cannot be greater than 100%. Each alternative can be represented by an expected value (Figure 22) (Ivan Damnjanovic, unpublished course notes from CVEN 349 Civil Engineering Project Management, 2011; Ostrom and Wilhelmsen 2012).

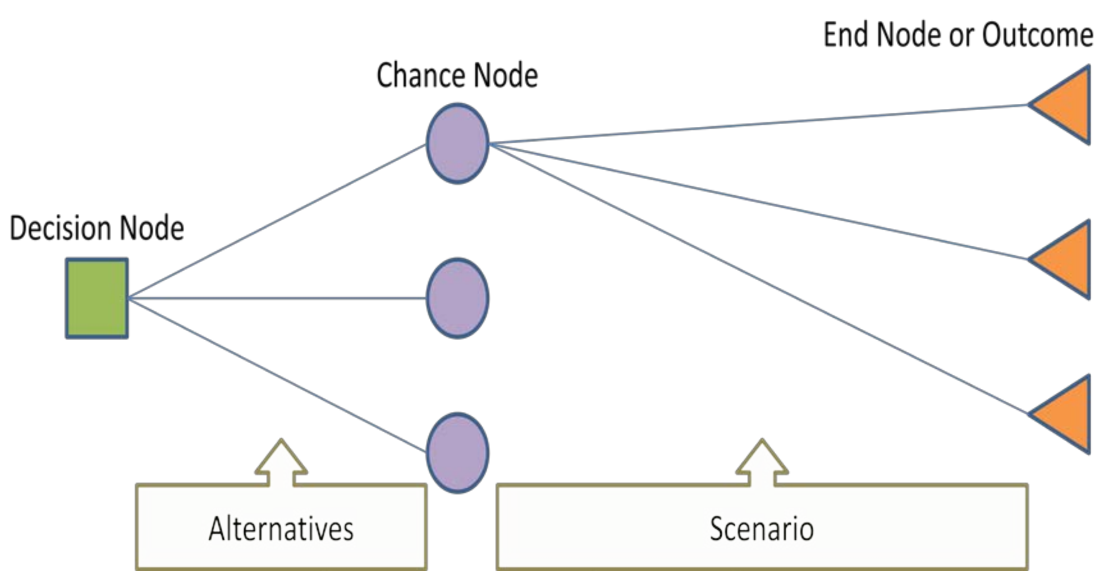


Figure 22. Decision Tree Analysis (DTA) Concept (adapted from Ivan Damnjanovic, unpublished course notes from CVEN 349 Civil Engineering Project Management, 2011; Ostrom and Wilhelmsen 2012)

For example, for an alternative that has three potential outcomes, the expected value, E(x), can be represented by:

$$E(x) = \sum_{n=1}^{3} Outcome_n \times Associated\ Probability_n$$

The expected values are often used to determine which is the best alternative. In this case of two alternatives of IBS and NIBS, the best alternative is the lowest expected annual maintenance costs. The annual costs are then estimated for a 25-45 year lifespan. Therefore, the difference in expected values of long term maintenance costs can be represented as a cost savings:

$$E_{25\ year\ lifespan}(Savings) = 25 \times |E(NIBS) - E(IBS)|$$

$$E_{45\ year\ lifespan}(Savings) = 45 \times |E(NIBS) - E(IBS)|$$

However, there is also a cost for construction of each alternative. The cost savings can then be compared with the construction cost estimate, or expected value of the cost premium to build IBS. Construction cost estimate for IBS is cited as 2-2.5% of a conventional hospital, or NIBS (Post and Kohn 1995). The range from larger to smaller hospitals through commercially available cost estimation software is calculated to be 1.6-4.2% (RSMeans 2012). It is assumed that although these estimates are not perfect, they are adequate to be used for comparison when giving consideration to long term savings. Detailed information on the construction cost estimates used for ranges of IBS construction cost premiums is shown in Appendix E.

Maintenance costs are outcomes of U.S. Army hospitals IBS and NIBS data obtained from DMLSS. In any U.S. Army hospital, there is both scheduled and unscheduled maintenance required. The cumulative distributions were used to determine expected values for scheduled and unscheduled maintenance of IBS and NIBS facilities based upon a three point estimate, including the mean and two extremes.

Cumulative probability distribution of costs for scheduled maintenance show data from IBS in blue and data from NIBS in red (Figure 23). When the distribution reaches 100% earlier along the curve, there is less variation in cost and the cost is lower than if the distribution reaches 100% later along the curve. NIBS increases sooner than IBS at the lower costs along the curve. However, at the higher costs along the curve, IBS approaches 100% sooner than NIBS, except for electrical.

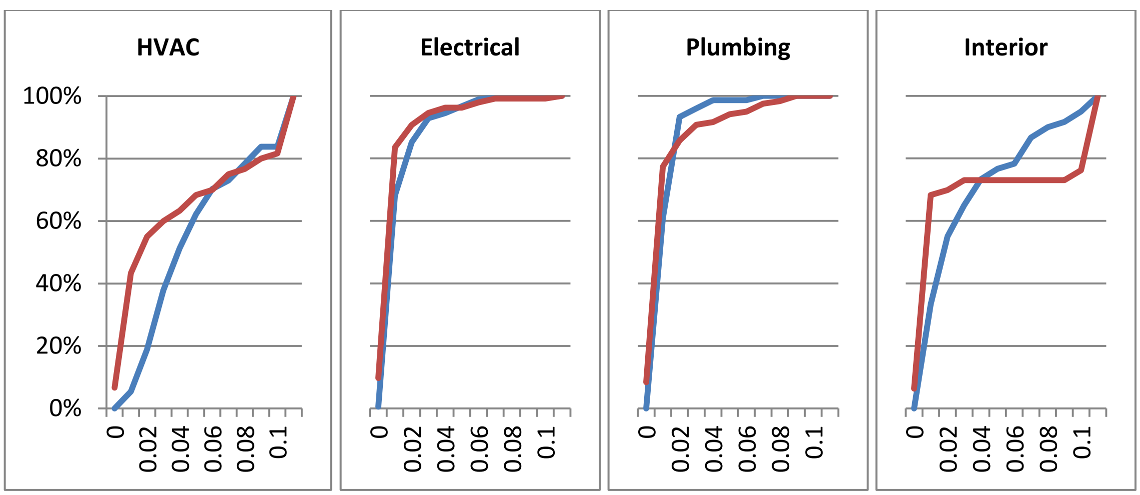


Figure 23. Cumulative Probability Distribution for Scheduled Maintenance

Cumulative probability distribution of costs for unscheduled maintenance follow the same rationale as for scheduled maintenance (Figure 24). In each building system, IBS approaches 100% sooner along the curve than does NIBS. This means that the NIBS data shows expending a greater percentage of costs at higher values.

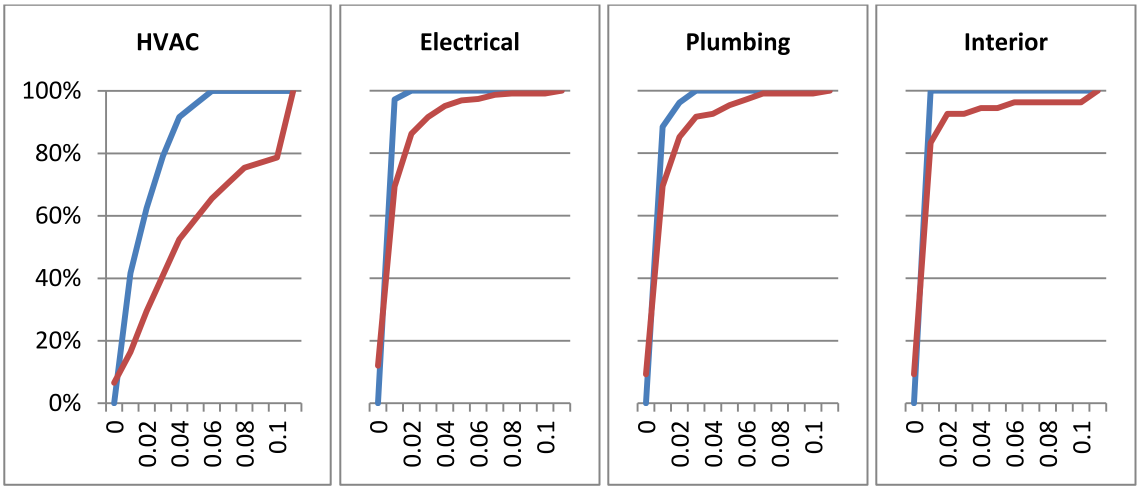


Figure 24. Cumulative Probability Distribution for Unscheduled Maintenance

Based upon the rank and percentile of the cumulative probability distribution of costs, outcomes were delineated based on a three-point estimate into high, medium, and low (Table 8).

Three possible outcomes (high, medium, and low) are considered, with 25%, 50%, and 25% probability, respectively. Assuming each facility type will require both scheduled and unscheduled maintenance, there are nine possible outcome, or end node combinations for each facility type (alternative). With two alternatives, there are eighteen combinations per building system.

Table 8. Three-Point Estimate of Costs

H,S,IBS	AUC	Percent	E,S,IBS	AUC	Percent	P,S,IBS	AUC	Percent	I,S,IBS	AUC	Percent
high	0.1079	88.8%	high	0.023	87.8%	high	0.0184	87.6%	high	0.0753	88.1%
medium	0.038	50.0%	medium	0.006	50.2%	medium	0.007	50.6%	medium	0.0159	50.8%
low	0.0183	13.8%	low	0.0006	12.7%	low	0.0025	13.6%	low	0.0009	13.5%

H,S,NIBS	AUC	Percent	E,S,NIBS	AUC	Percent	P,S,NIBS	AUC	Percent	I,S,NIBS	AUC	Percent
high	0.3137	88.1%	high	0.0162	87.7%	high	0.0212	88.1%	high	0.3666	88.7%
medium	0.0174	50.8%	medium	0.002	50.0%	medium	0.003	50.0%	medium	0.0051	50.0%
low	0.0015	13.5%	low	3E-05	12.7%	low	0.0002	12.7%	low	0.0002	12.9%

H,U,IBS	AUC	Percent	E,U,IBS	AUC	Percent	P,U,IBS	AUC	Percent	I,U,IBS	AUC	Percent
high	0.0389	91.3%	high	0.006	88.5%	high	0.0062	88.0%	high	0.0005	100.0%
medium	0.0136	52.1%	medium	0.0005	51.4%	medium	0.0013	52.0%	medium	6E-05	50.0%
low	0.0003	13.0%	low	3E-05	14.2%	low	0.0001	16.0%	low	4E-05	16.6%

H,U,NIBS	AUC	Percent	E,U,NIBS	AUC	Percent	P,U,NIBS	AUC	Percent	I,U,NIBS	AUC	Percent
high	0.2151	88.3%	high	0.0228	87.5%	high	0.025	87.8%	high	0.0153	88.6%
medium	0.0389	50.0%	medium	0.004	50.0%	medium	0.0035	50.4%	medium	0.002	50.9%
low	0.0062	13.3%	low	8E-06	12.5%	low	7E-05	13.0%	low	4E-05	13.2%

Legend: H=HVAC, E=Electrical, P=Plumbing, I=Interior. S=Scheduled, U=Unscheduled.
AUC=Adjusted Unit Cost

The DTA for each building system results in the following expected values for annual maintenance costs (adjusted unit costs ($/sf)) (Table 9):

Table 9. Expected Values for Annual Maintenance Costs

Expected Values:	HVAC	Electrical	Plumbing	Interior
IBS	0.067	0.011	0.011	0.027
NIBS	0.162	0.013	0.015	0.099

Therefore, expected lifecycle savings for each building system are calculated as follows:

$$E_{25\ year\ lifespan}(Savings) = 25 \times |E(NIBS) - E(IBS)|$$

$$E_{45\ year\ lifespan}(Savings) = 45 \times |E(NIBS) - E(IBS)|$$

4.7.2. Cost Premium and Maintenance Savings Comparison

A comparison of the expected initial costs to the expected life savings is shown by building systems, with the exception of interior (Table 10).

Table 10. Cost and Savings Comparison

IBS Lifecycle Savings:	HVAC	Electrical	Plumbing
25 year lifespan	2.38	0.05	0.10
45 year lifespan	4.28	0.09	0.18

IBS Premiums:	HVAC	Electrical	Plumbing
lowest	0.50	0.46	0.38
medium	0.78	0.71	0.59
highest	1.43	1.31	1.08

Although electrical and plumbing do not show an overall savings with this data set, it is important to remember that the average adjusted unit costs for electrical and plumbing were 7% and 8% respectively, while HVAC made up 50%. The ability to impact future costs based upon design decisions made in the present, should certainly not neglect building systems that are expected to be more costly for maintenance.

Another way to consider this is to sum the building systems (HVAC, electrical, and plumbing) (Table 11). RSMeans did not have a line item for interior works. Thus an IBS cost premium was not calculated in this area and the interior building system was excluded from this comparison.

Table 11. Cost and Savings Comparison (Three Building System Cumulative)

IBS Lifecycle Savings:	
25 year lifespan	2.53
45 year lifespan	4.55
IBS Premiums:	
lowest	1.33
medium	2.08
highest	3.82

This range shows that the amount of cost savings is estimated to be up to three and a half times what would be paid for the IBS premium (Figure 25).

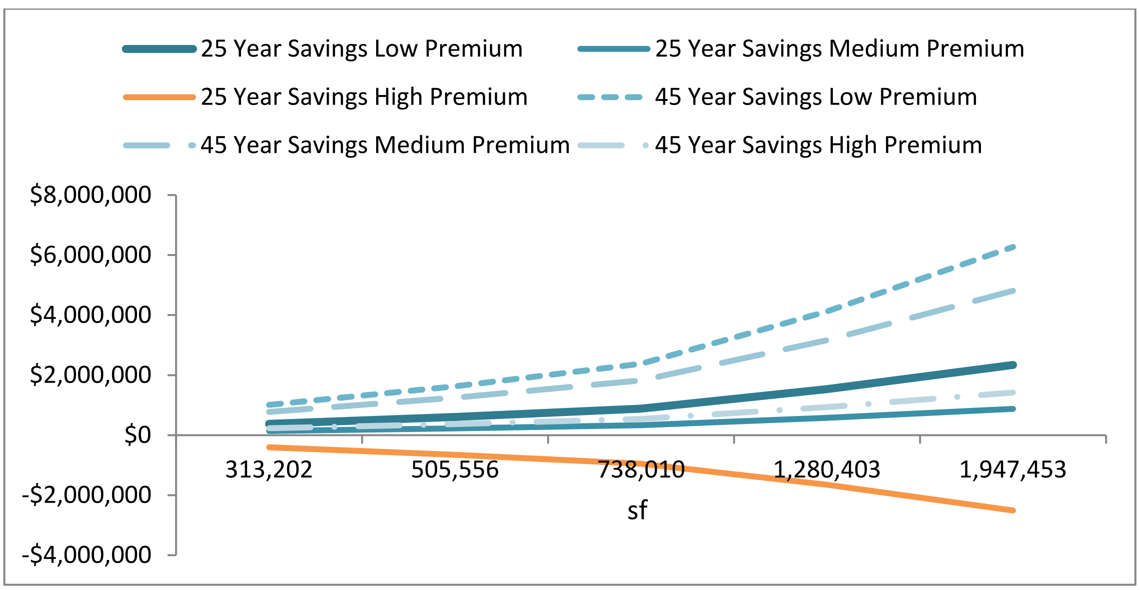


Figure 25. Estimate of Lifecycle Savings (Difference of Savings and Premium)

Lines above the x-axis indicate the savings is greater than the premium cost. The one line below the x-axis indicates savings would not be greater than the premium cost. It would not be recommended to negotiate a high premium for a shorter lifespan (25 year) or for a large (sf) hospital. This shows that in all but the highest IBS premium (recall was estimated for the smallest hospital size), it is expected to cost less to build a hospital with IBS design than it would cost to maintain it for a 25-45 year lifespan. Additional data should be collected on construction cost premiums to verify the cost estimates cited in this study.

5. CONCLUSIONS

5.1. Introduction

Every U.S. Army hospital has its own particular nuances to operations and facility maintenance due to a variety of reasons which can influence costs and time expenditures. Yet, organizationally these facilities have all adopted DMLSS to capture the facility maintenance cost and time data. Under the assumption that the data set was large enough and a uniform sample of the population, the risk of influence by these other factors can be mitigated. Similar investigation of other relationships can explore differences between IBS and NIBS for verification and validation purposes. This study demonstrated the financial benefits of building a U.S. Army hospital with IBS design.

5.2. Summary

The data set pulled from DMLSS included the most number of records from the electrical building system, but the HVAC building system was the most costly on the average.

Considerations were made for analyzing the data separately for fiscal year and facility age, but each analysis showed a generally higher trend for both costs and time spent on facility maintenance for a NIBS (or conventional) U.S. Army hospital than did IBS.

Expenditures in time and money expended in facility maintenance for U.S. Army hospitals were variable from different building systems, but the slope of IBS was generally lower than the slope of NIBS, meaning that less money was spent per time for IBS.

As time was generally correlated with costs, the study shifted to focus on a decision analysis based upon expected costs. With smaller yearly budgets, it may be difficult to program for building hospitals with IBS because of the cost premiums, but decision makers should closely consider the impacts to the long term maintenance budget. With aging facilities, it is said that "management has realized that O&M costs are (or could be) 'eating their bottom-line lunch';" and how better to combat these costs than to provide for a more sustainable design (Smith and Hinchcliffe 2004). The evidence in the data collected from this study shows that there is a clear financial benefit to IBS design. When comparing estimated initial construction costs to potential savings over a facility lifecycle, it was found that the difference between NIBS facility maintenance costs and IBS facility maintenance costs for a 25-45 year lifespan provided an overall savings that outweighed the initial IBS premium construction cost.

5.3. Research Limitations and Assumptions

Data is assumed to be representative of comparable facilities. Building systems were identified that were assumed to most likely represent areas that could be directly impacted by utilizing an IBS design. The data analysis is limited to the selected facilities and building system groupings, and results could change if the selection of facilities or systems were different. It should be noted that not every facility is exactly the same and the data gathered are susceptible to confounding factors. For example, major building components that have to be maintained in a facility may come from differing manufacturers with different past performance. This can affect the number of maintenance hours needed for the major building component.

It is assumed that data entry personnel had full opportunity to input the information into the database for each fiscal year. The exceptions are the U.S. Army hospitals at Fort Bragg (built in 1998) and Fort Wainwright (built in 2007). It is assumed that for these two facilities, data entry personnel had full opportunity to input the information into the database for each fiscal year since the facility was built. It is further assumed that the data entry personnel were equally supported and maintenance personnel had equal technical expertise is performing both scheduled and unscheduled maintenance. It should be noted that this may not always be the case. Organizational leadership can affect differences in levels of support or prioritization of database management for data entry personnel and budget availability for maintenance personnel. This can affect maintenance performed in the facility and may not be the same for each of the facilities.

Data represents information from facilities located in different locations. It was assumed that information from the UFCs would be more appropriate to adjust data values than information from RSMeans. This is because the UFCs specified ACFs for particular military bases while RSMeans specified ACFs, or location factors, only for major cities. It should be noted that the U.S. Army hospitals at Fort Wainwright was the only facility located outside of the continental United States (CONUS) after screening criteria were applied.

It was assumed most appropriate to adjust data to values of 2012 NPV for comparison purposes.

Data represents information from facilities of different sizes. Although a correction factor was applied to normalize the data to unit cost and unit time, it is assumed economies of scale can affect building performance.

Data represents information from facilities that were built in different years, and thus represent different facility ages. It is assumed a facility will perform differently based upon its age.

Data is available as recorded, and often with missing information, or gaps. For example, each facility does not have data elements for every FY from 1997-2011. Similarly, each building system does not data elements for every FY from 1997-2011. More comprehensive data could have been used if, for example, the hospitals at Landstuhl and Tripler were one whole facility rather than being represented by many buildings. Another example is that the Madigan hospital in Fort Lewis, WA (Joint Base Lewis-McChord) did not use DMLSS as the facility maintenance database at the time of this data collection.

5.4. Recommendations and Areas for Further Research

There are several opportunities for further research identified during the course of this study.

With respect to facility maintenance, further investigation should be performed into the extreme data outliers and missing information gaps to help better understand the reasons for variance. If there is missing data that is later found, or data that had been recorded manually, then it should be input into DMLSS per resource availability. For outliers that trend with a specific facility, further investigation should determine what factors may be causing the greater variance. There may be a re-education requirement with the DMLSS system, to ensure affected personnel organization-wide have similar understanding of data input procedures. As DMLSS is a "defense" (DoD) system and not just an "Army" system, not only all U.S. Army hospitals, but also all DoD hospitals should be utilizing the standard software platform (DMLSS). If another system is adopted as the standard in the future, then all facilities should follow migration to the standard. This affects the ability to make fair comparisons for purposes of uniformity in both data collection and performance assessments.

Throughout the literature search, other areas for comparing IBS to NIBS were identified including: infection control, flexibility, disruption, and construction. Identifying, gathering, and analyzing quantitative data in these areas can help to provide evidence to more fully validate and verify the benefits of adopting IBS as the standard of design supporting the "MHS guiding principles (including World-Class, Evidence Based Design (EBD), Sustainable Design, and Life-Cycle Facility Management)" (DoD 2012).

5.5. Conclusions

Based upon the findings in this study, it is concluded that the U.S. Army hospitals that were investigated with an IBS-designed facility operate at an overall lower facility maintenance cost (and time) than do the conventional (NIBS) counterparts.

This does not mean that there is not a cost premium to constructing the IBS design. However, decision analysis based upon commercially-available cost data demonstrates the advantages of IBS. Comparing the cost of the premium with the savings provided from expected values of IBS over the facility lifespan shows that it is more economical to construct IBS than it is to pay the lifespan facility maintenance for NIBS for the facilities evaluated in this analysis. The amount of facility maintenance cost savings is estimated to be up to three and a half times what would be paid for the IBS premium.

The U.S. Army, along with the other services, are transitioning healthcare to governance under a defense health agency reported to “reach an initial operating capability by 2013, with full operating capability within 2 years” (GAO 2012). With the need to control costs, design of the defense healthcare infrastructure should be carefully monitored during the decision-making process to not just assess initial construction costs, but to include a full life-cycle assessment of costs. It is imperative that costs are fully captured to be able to provide a realistic model to decision-makers in the future.

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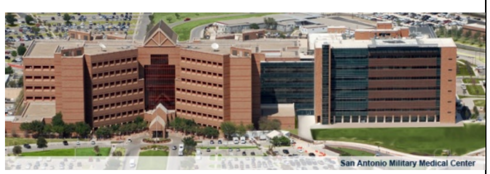
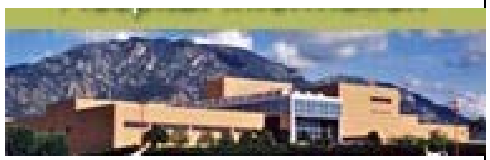
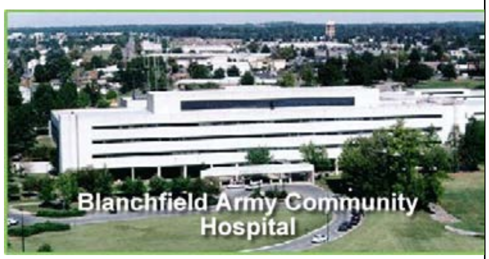
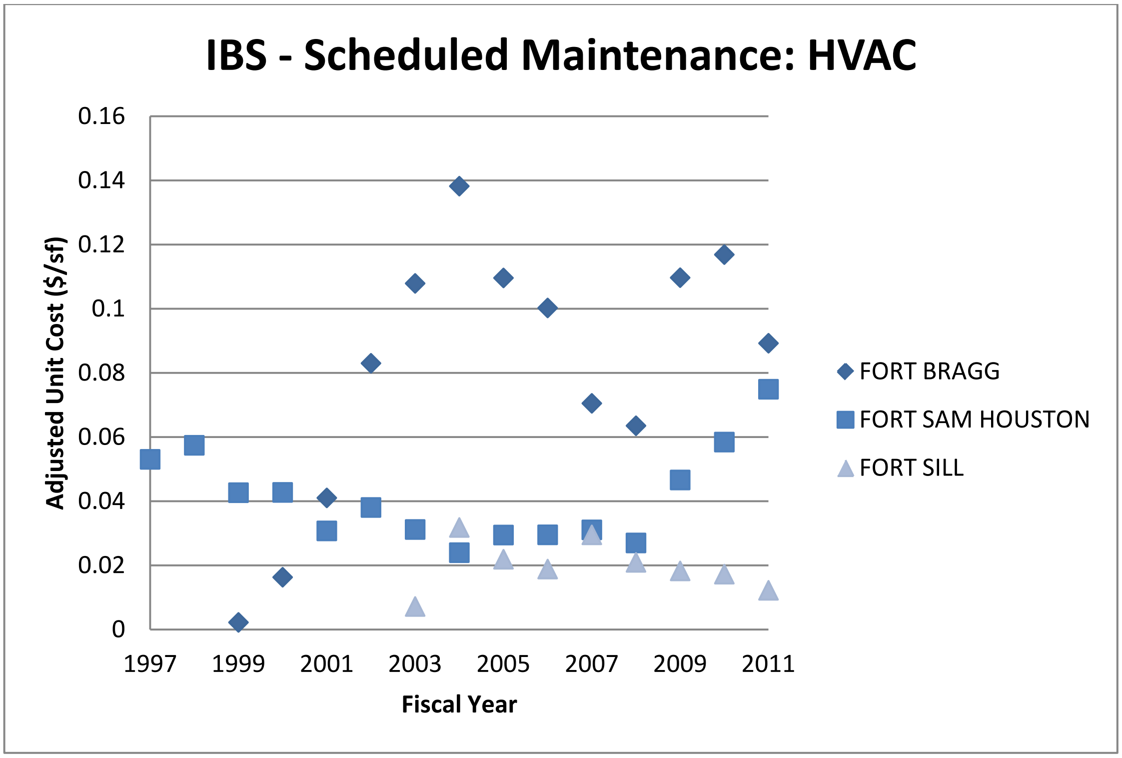
APPENDIX A. PHOTOS OF U.S. ARMY HOSPITALS UNDER CONSIDERATION

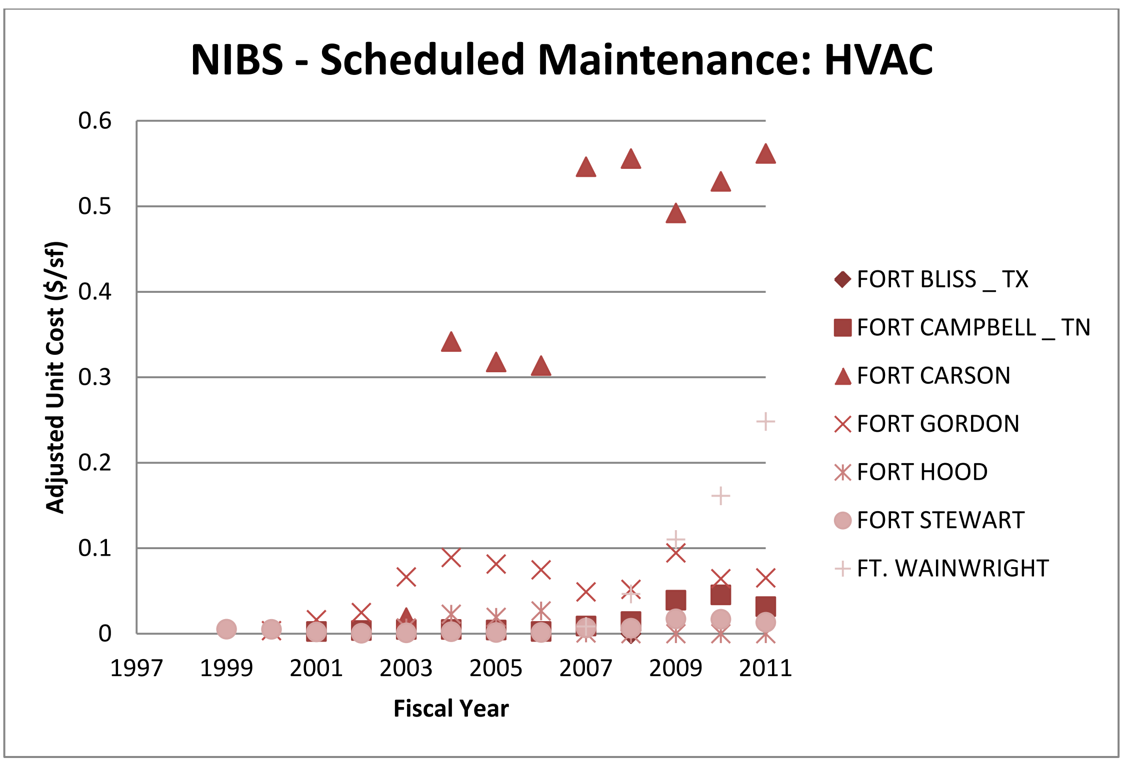
	Installation	Image	Name	Image Location	Date Web Modified	Web Location
1	Bragg		Womack	http://www.wamc.amedd.army.mil/visitors/PublishingImages/TownHall5Oct11/WAMC%20Town%20Hall%205%20OCT%2011%20%20vo3_1.jpg	5 October 2011	http://www.wamc.amedd.army.mil/visitors/Pages/TownHallSlides5Oct11.aspx
2	Sam Houston		SAMMC	http://www.bamc.amedd.army.mil/images/coto-bamc.jpg	8 February 2013	http://www.bamc.amedd.army.mil/
3	Tripler		Tripler	http://www.tamc.amedd.army.mil/residency/mchk-dm/images/tripler.jpg	No Date	http://www.tamc.amedd.army.mil/residency/mchk-dm/opportunities.htm
4	Landstuhl		Landstuhl	http://militarybases.com/images/bases/landstuhl.jpg	2012	http://militarybases.com/overseas/germany/lmrc/

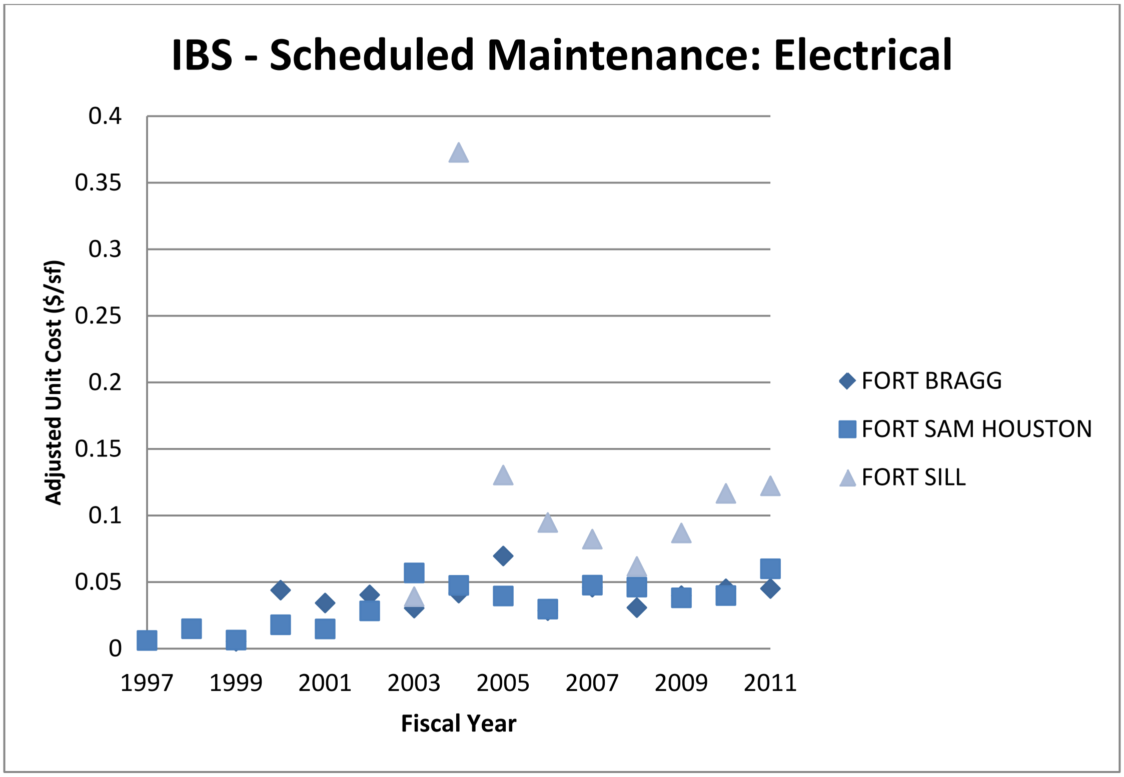
	Installation	Image	Name	Image Location	Date Web Modified	Web Location
5	Bliss		Beaumont	http://www.wbamc.amedd.army.mil/images/wbamcHospitalPhoto-1.png	31 January 2013	http://www.wbamc.amedd.army.mil/
6	Gordon		Eisenhower	http://offload.goarmy.com/amedd/health-care/facilities/dwight-d-eisenhower-army-medical-center/jcr:content/contentpar/header.header-amedd-whattoexpect-facilities-2.png	No Date	http://www.ddeamc.amedd.army.mil/default.aspx * http://www.goarmy.com/amedd/health-care/facilities/dwight-d-eisenhower-army-medical-center.html
7	Hood		Darnall	http://www.srmc.amedd.army.mil/img/Darnall.jpg	No Date	http://www.crdamc.amedd.army.mil/ * http://www.srmc.amedd.army.mil/XML_Banner.swf
8	Sill		Reynolds	http://www.rach.sill.amedd.army.mil/images/RACH.jpg	No Date	http://www.rach.sill.amedd.army.mil/

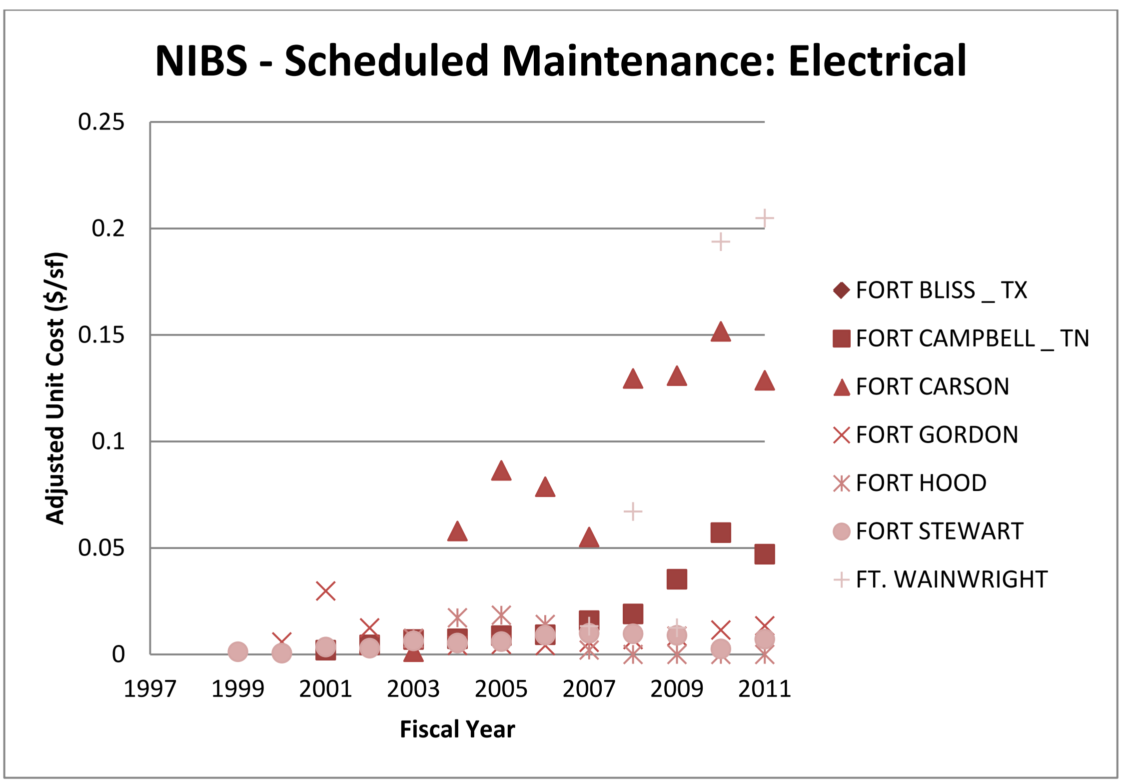
	Installation	Image	Name	Image Location	Date Web Modified	Web Location
9	Carson		Evans	http://www.evans.amedd.army.mil/root/images/hospitalInfo.jpg	15 February 2013	http://www.evans.amedd.army.mil/
10	Campbell		Blanchfield	http://www.srmc.amedd.army.mil/img/bach.jpg	No Date	http://www.campbell.amedd.army.mil/ * http://www.srmc.amedd.army.mil/XML_Banner.swf
11	Stewart		Winn	http://www.srmc.amedd.army.mil/img/winn.jpg	No Date	http://www.winn.amedd.army.mil/ * http://www.srmc.amedd.army.mil/XML_Banner.swf
12	Wainwright		Bassett	http://www.alaska.amedd.army.mil/photos/BACH_Statue_Drive.jpg	20 December 2010	http://www.alaska.amedd.army.mil/

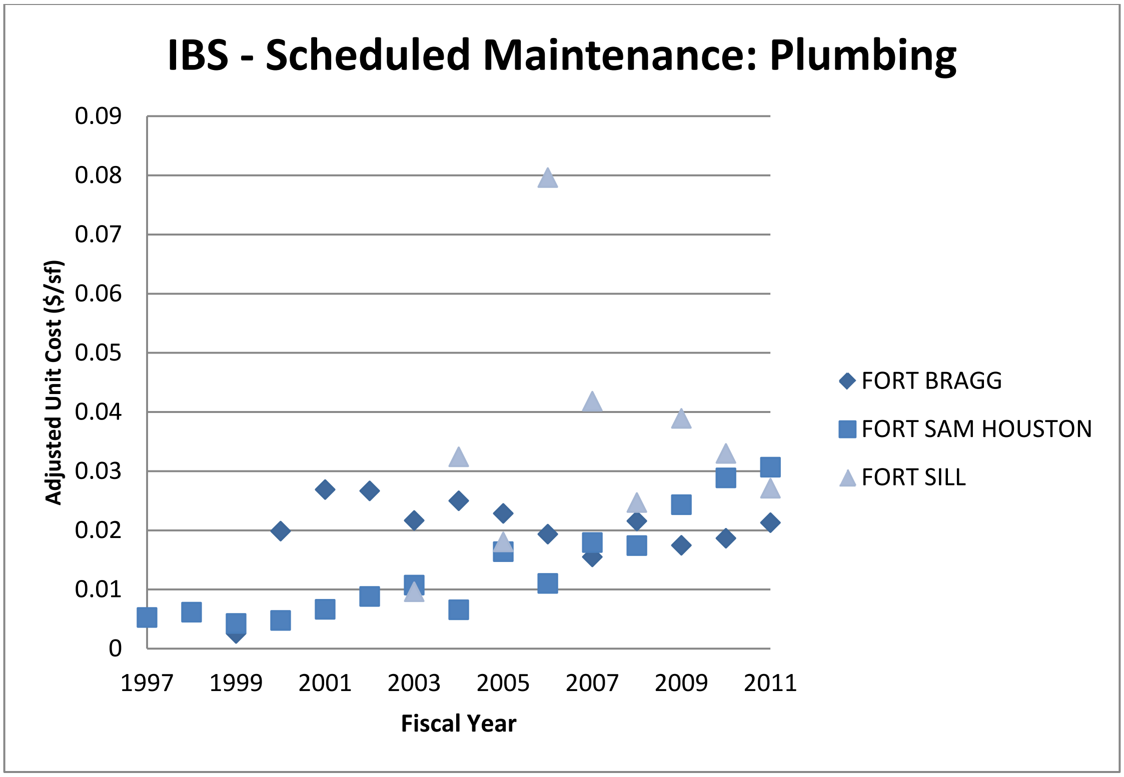
APPENDIX B. DISTRIBUTION OF MAINTENANCE OVER FISCAL YEAR

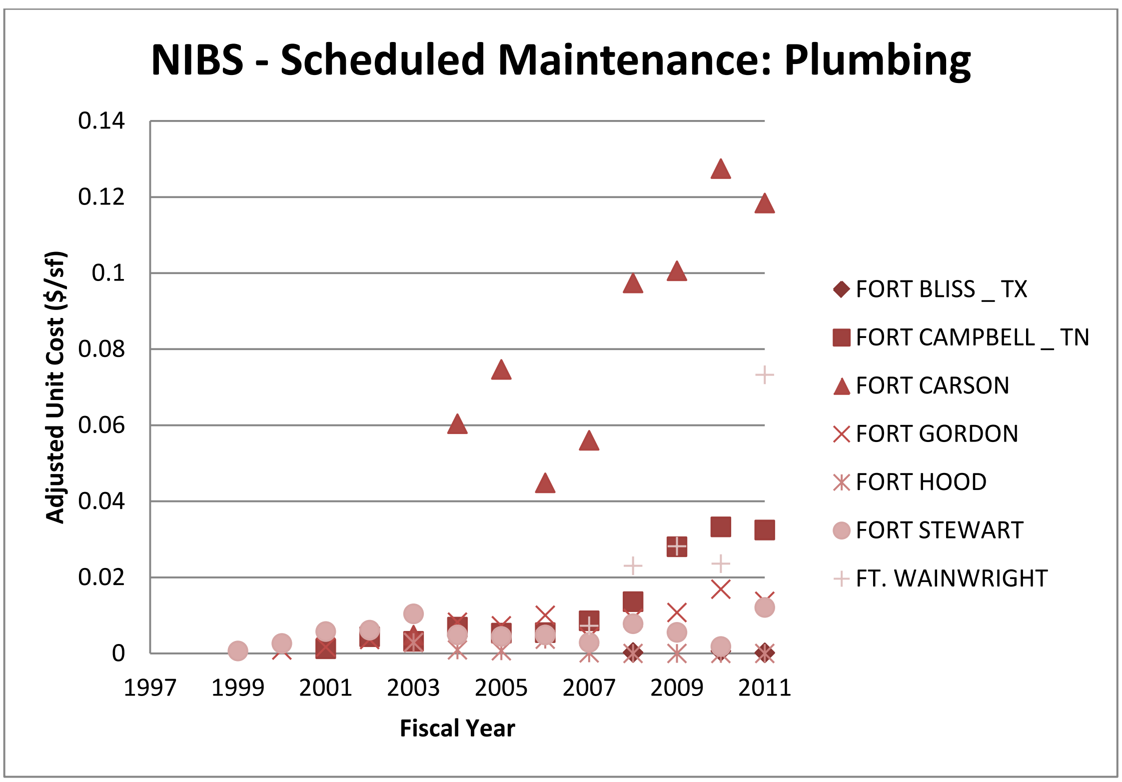


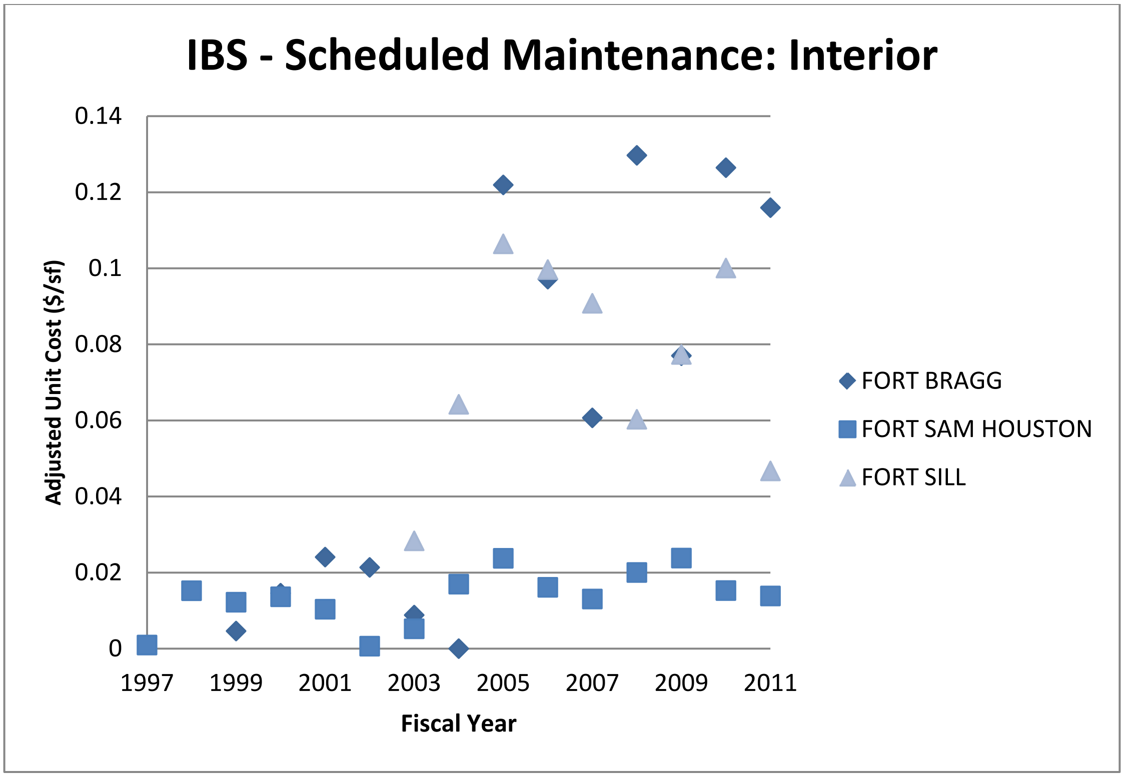


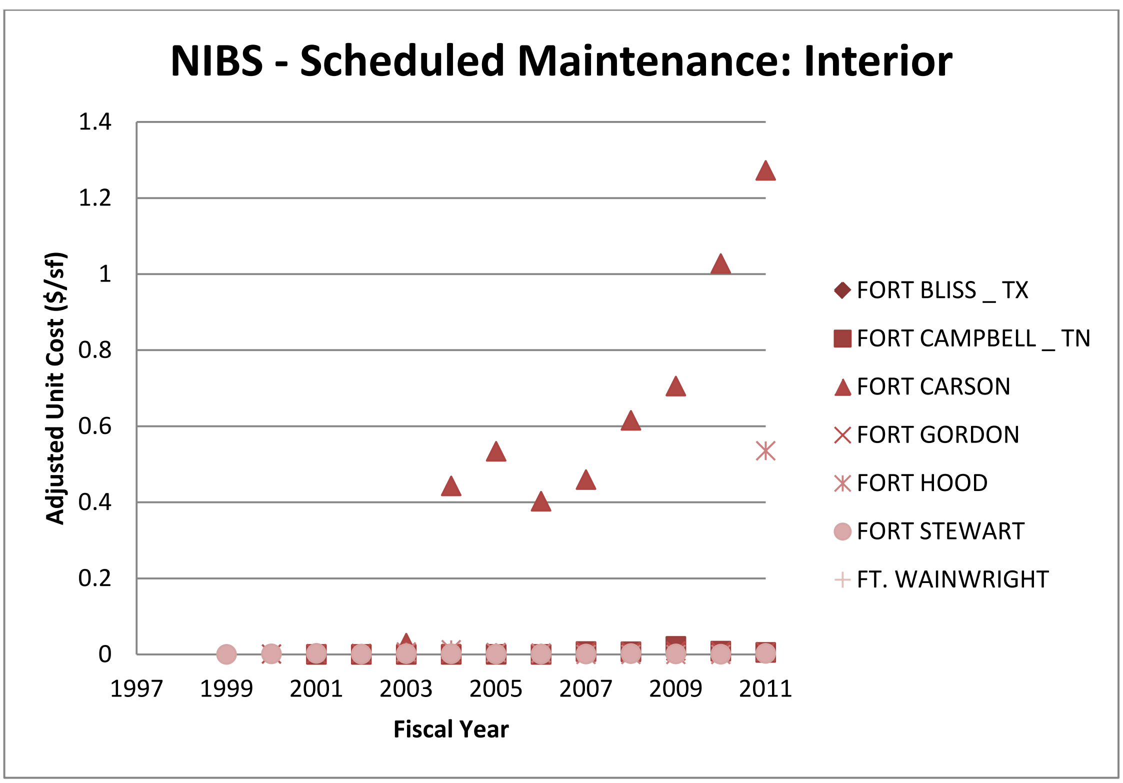

IBS - Scheduled Maintenance: Electrical
Adjusted Unit Cost ($/sf)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

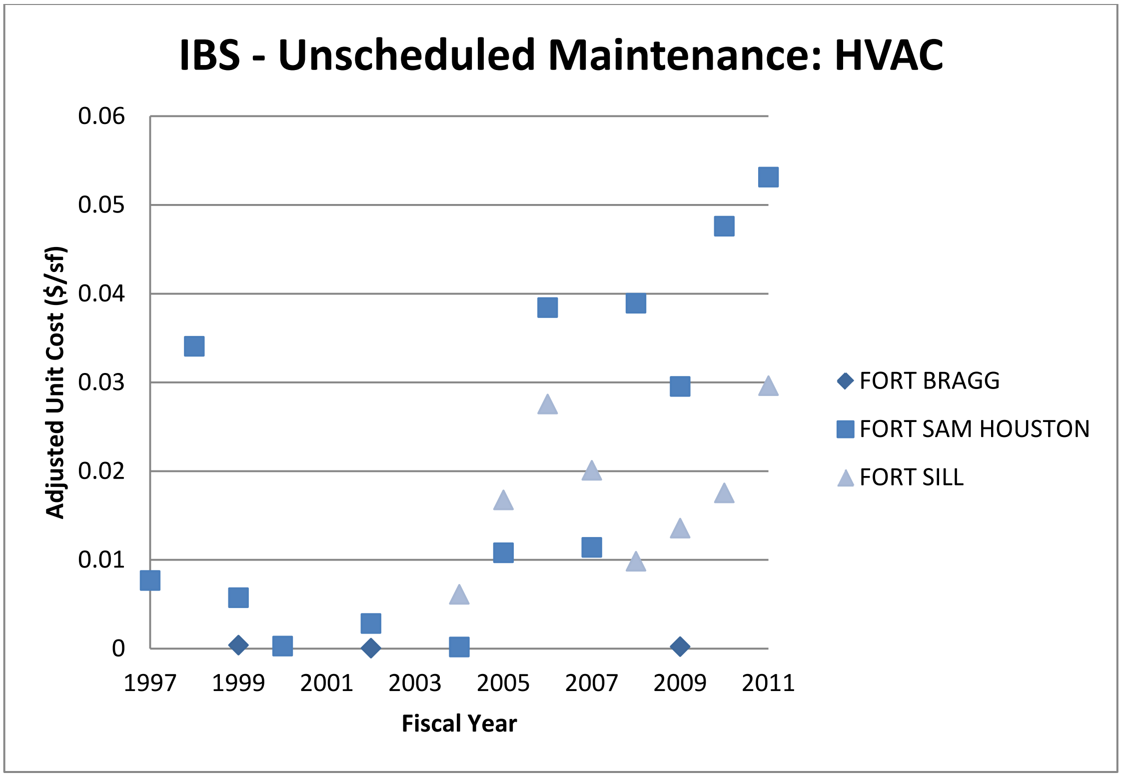

NIBS - Scheduled Maintenance: Electrical
Adjusted Unit Cost ($/sf)
0.25
0.2
0.15
0.1
0.05
0
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT

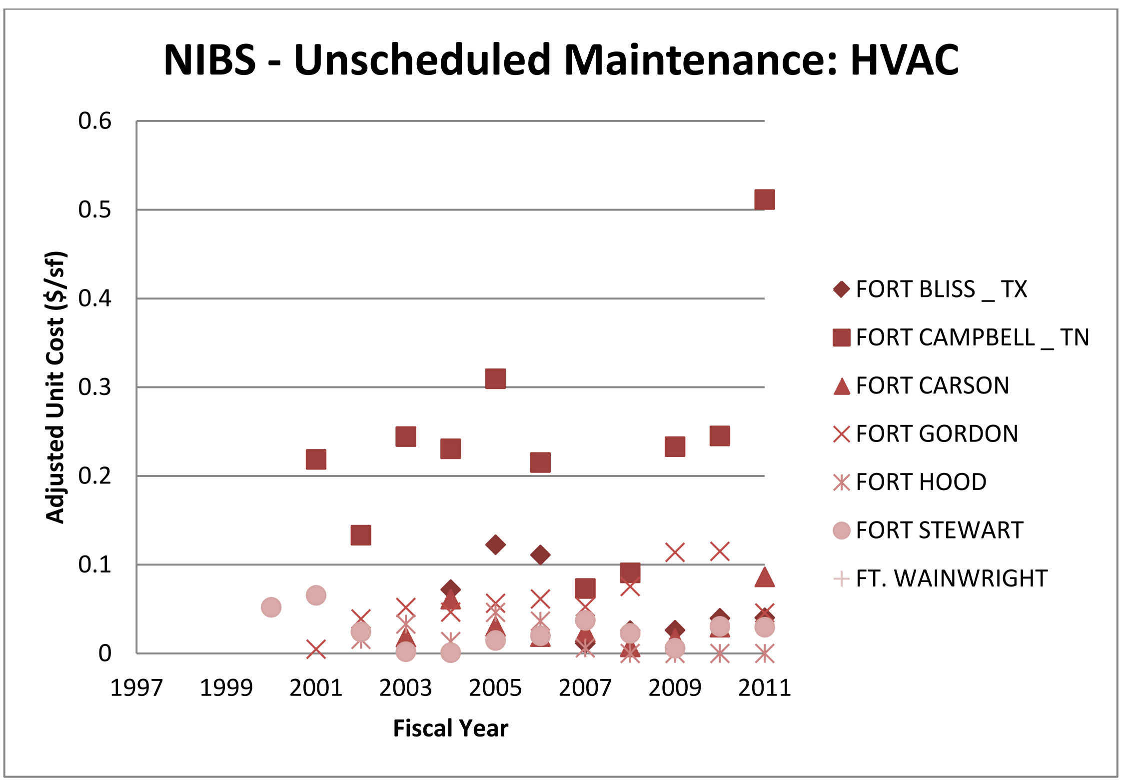

IBS - Scheduled Maintenance: Plumbing
Adjusted Unit Cost ($/sf)
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

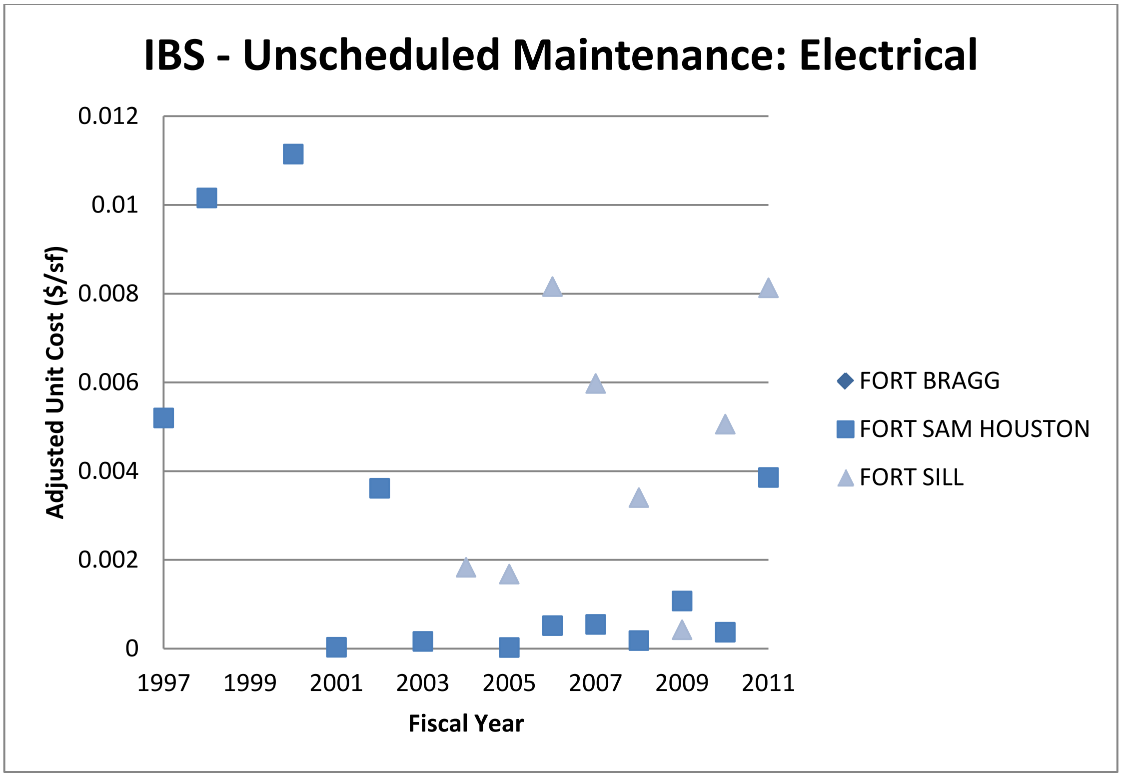

NIBS - Scheduled Maintenance: Plumbing
Adjusted Unit Cost ($/sf)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT

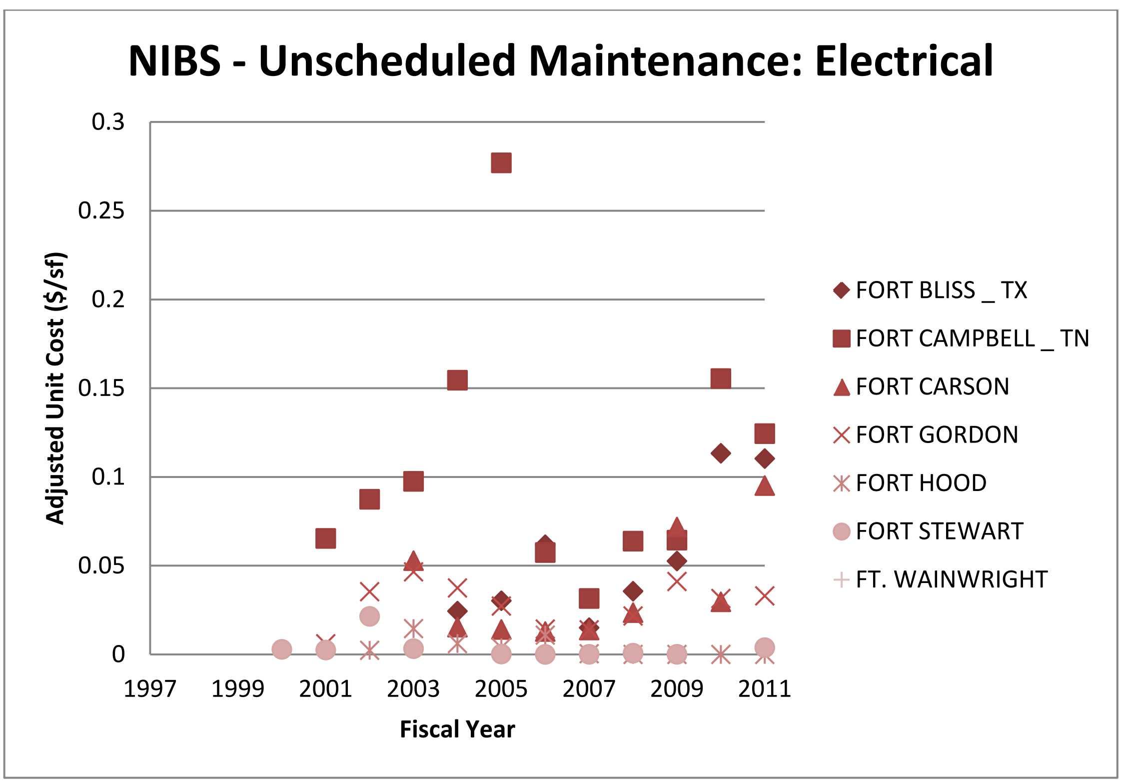

IBS - Scheduled Maintenance: Interior
Adjusted Unit Cost ($/sf)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

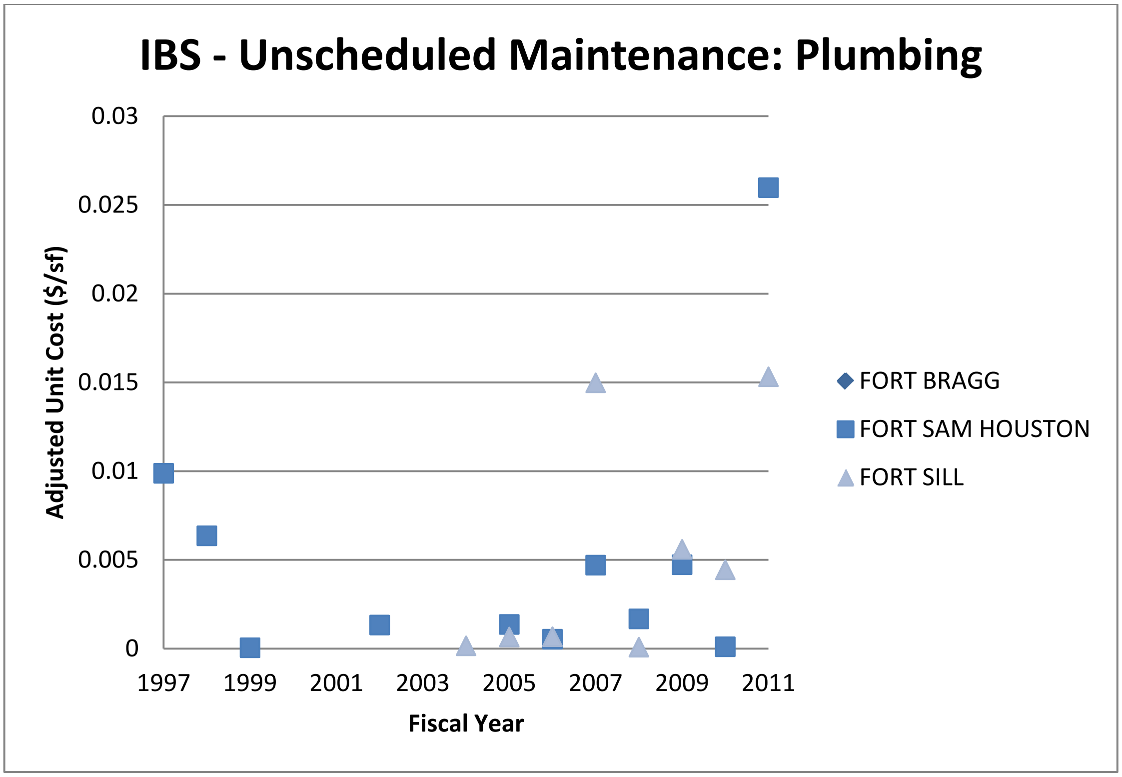

NIBS - Scheduled Maintenance: Interior
Adjusted Unit Cost ($/sf)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT

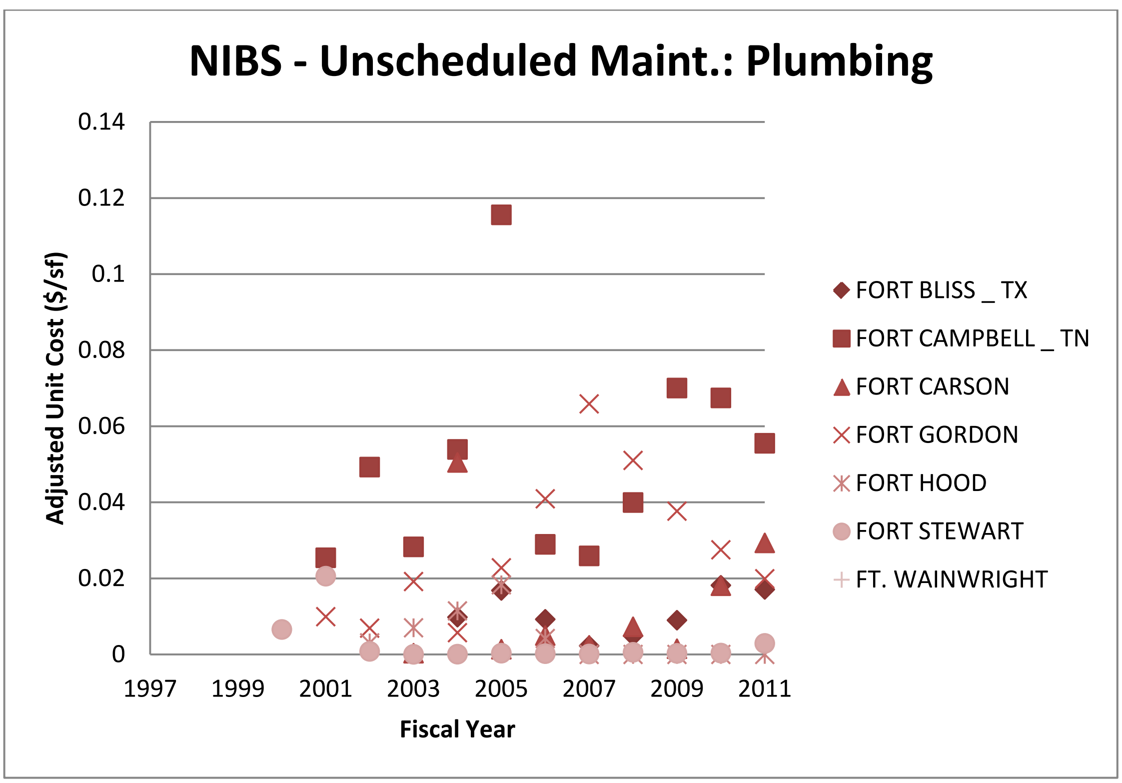

IBS - Unscheduled Maintenance: HVAC
Adjusted Unit Cost ($/sf)
0.06
0.05
0.04
0.03
0.02
0.01
0
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

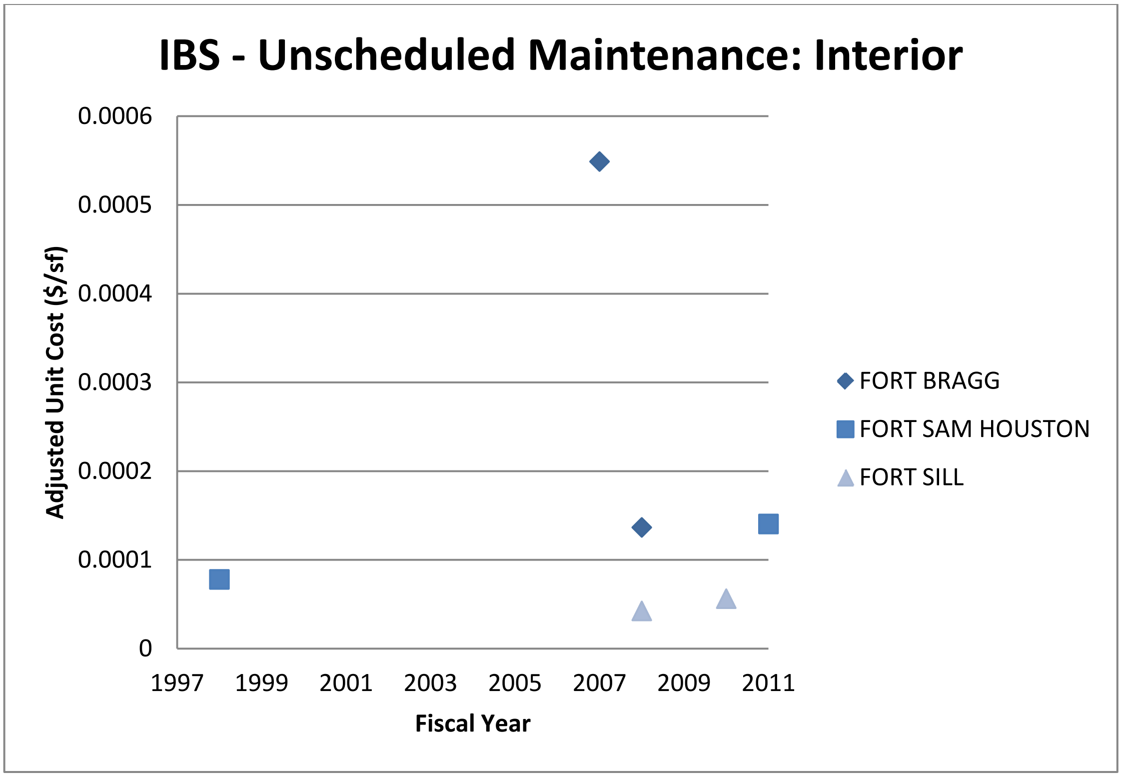

NIBS - Unscheduled Maintenance: HVAC
Adjusted Unit Cost ($/sf)
0.6
0.5
0.4
0.3
0.2
0.1
0
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT

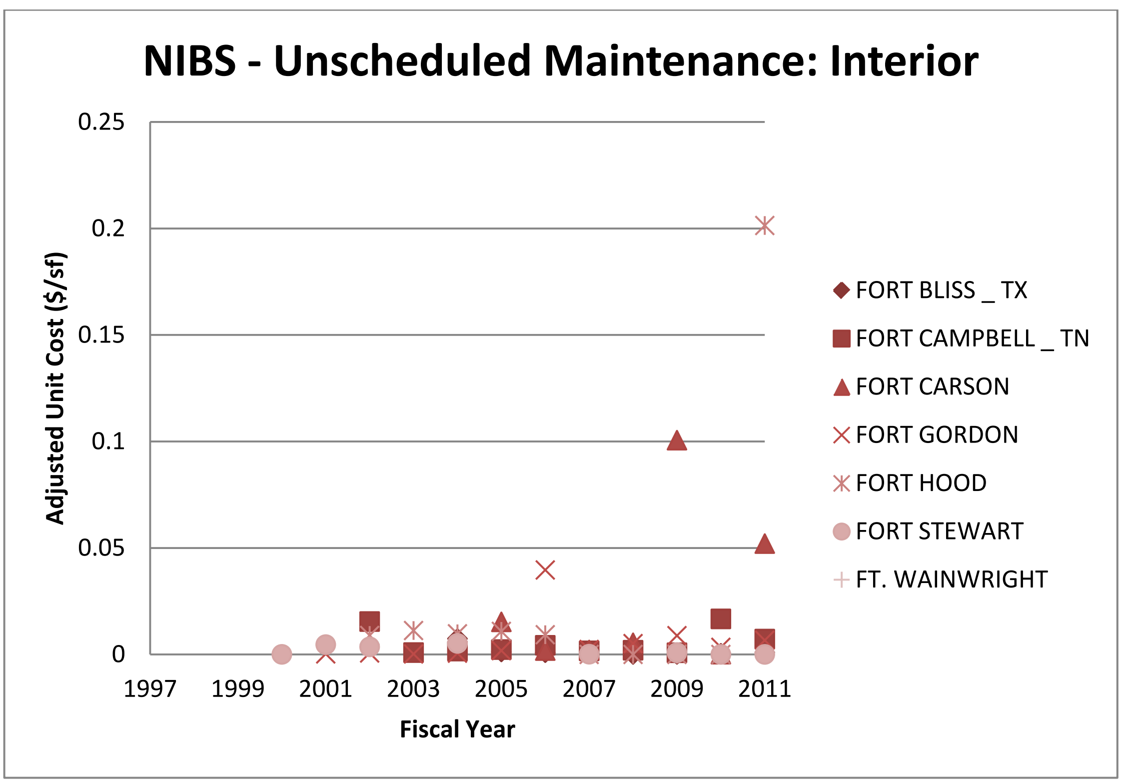

IBS - Unscheduled Maintenance: Electrical
Adjusted Unit Cost ($/sf)
0.012
0.01
0.008
0.006
0.004
0.002
0
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

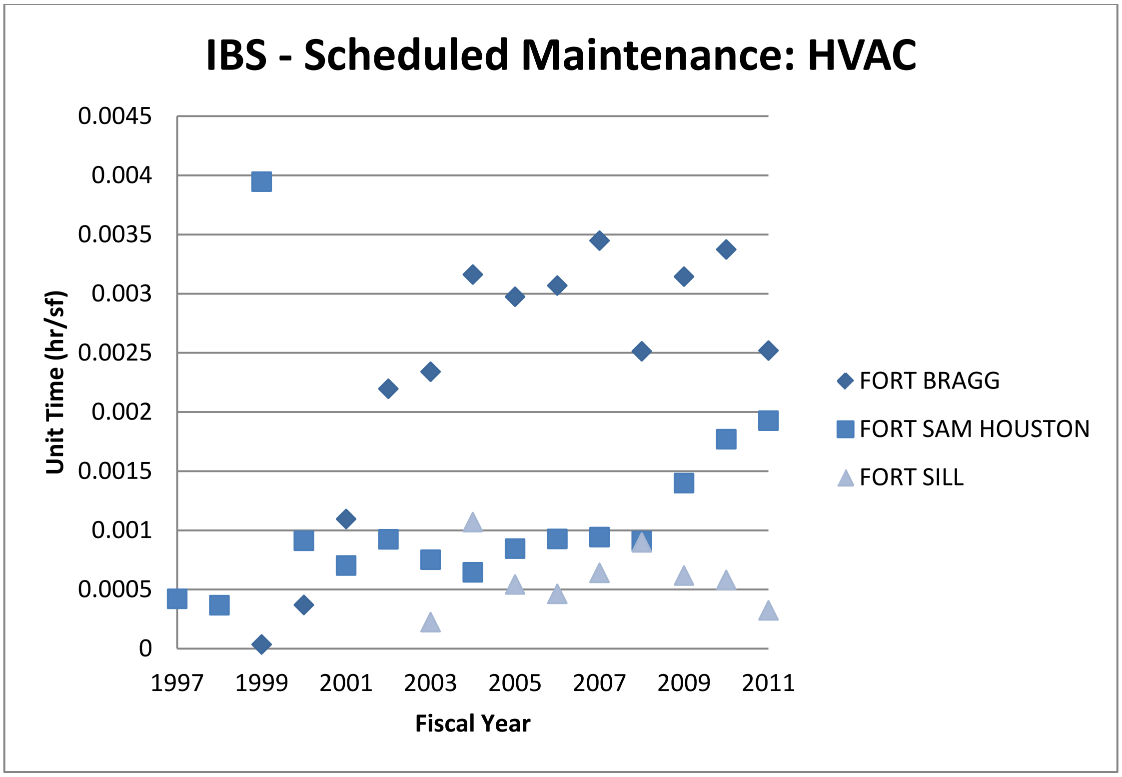

NIBS - Unscheduled Maintenance: Electrical
Adjusted Unit Cost ($/sf)
0.3
0.25
0.2
0.15
0.1
0.05
0
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT

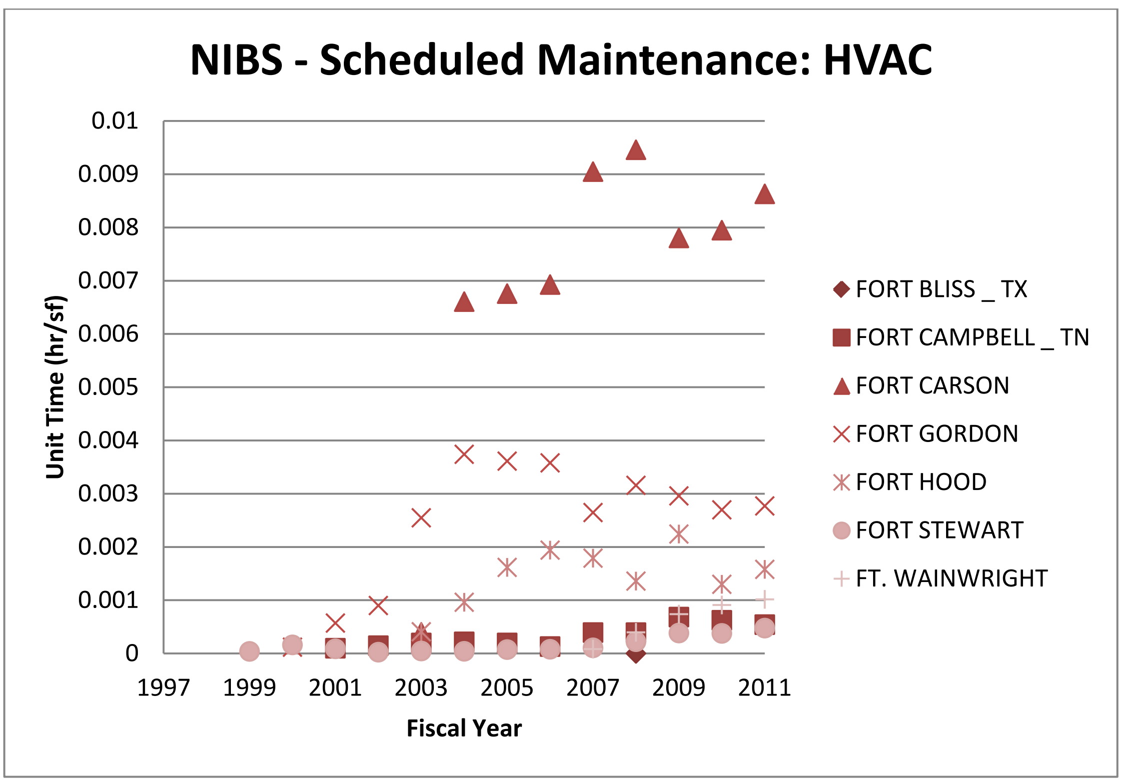

IBS - Unscheduled Maintenance: Plumbing
0.03
0.025
0.02
0.015
0.01
0.005
0
Adjusted Unit Cost ($/sf)
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

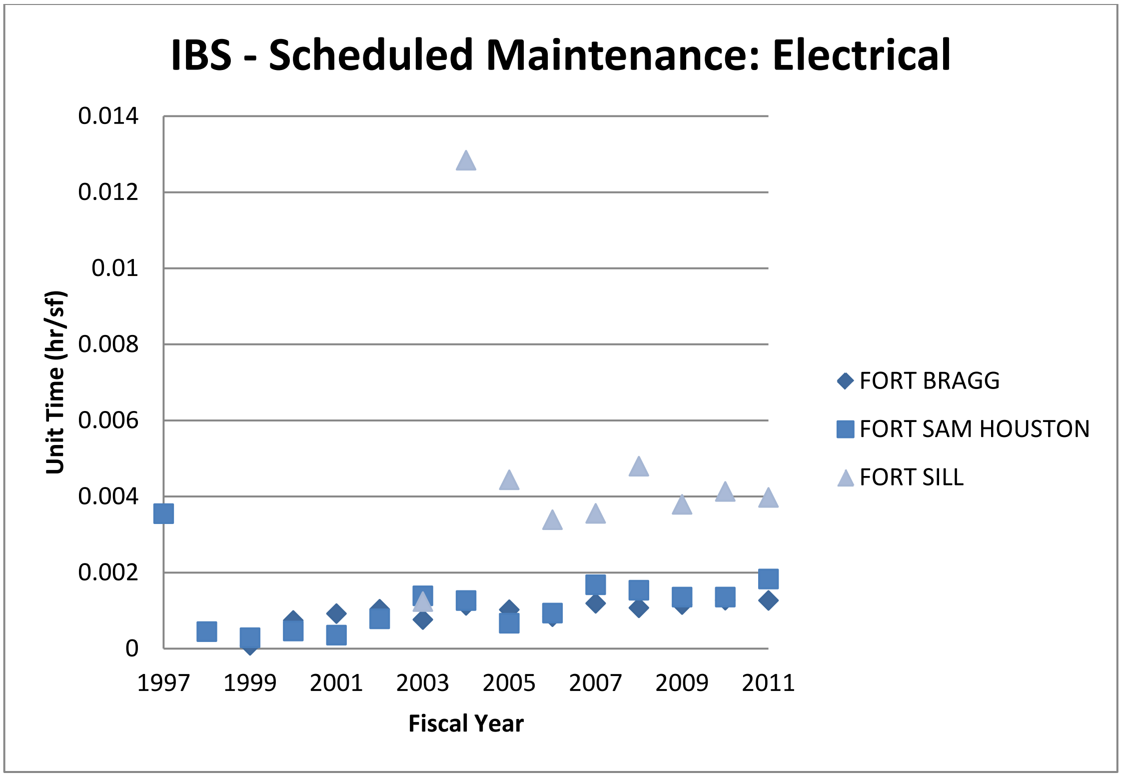

NIBS - Unscheduled Maint.: Plumbing
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Adjusted Unit Cost ($/sf)
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT

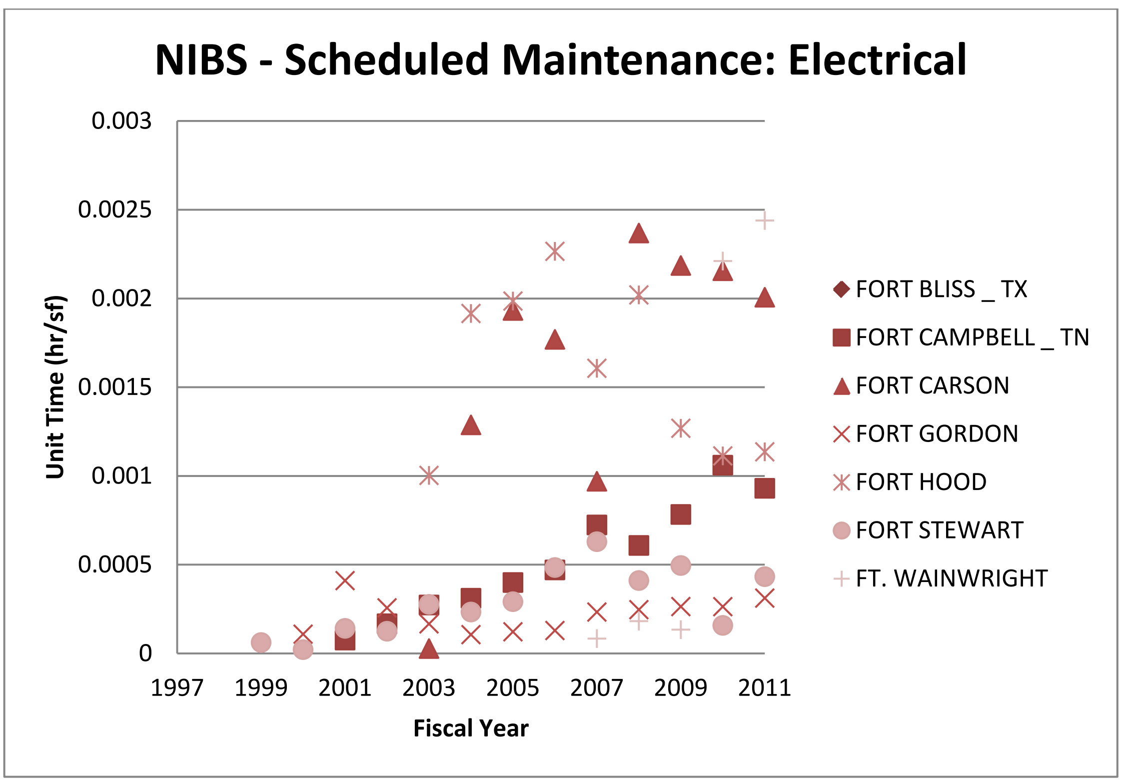

IBS - Unscheduled Maintenance: Interior
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0
Adjusted Unit Cost ($/sf)
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

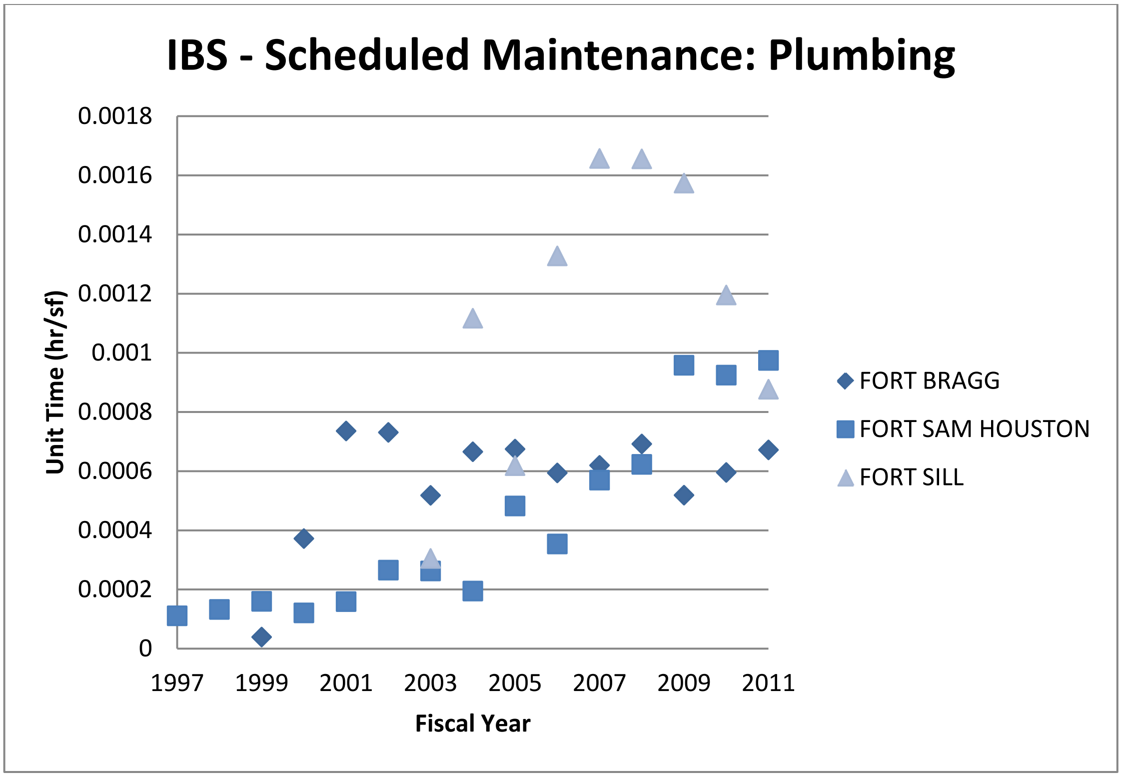

NIBS - Unscheduled Maintenance: Interior
0.25
0.2
0.15
0.1
0.05
0
Adjusted Unit Cost ($/sf)
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT

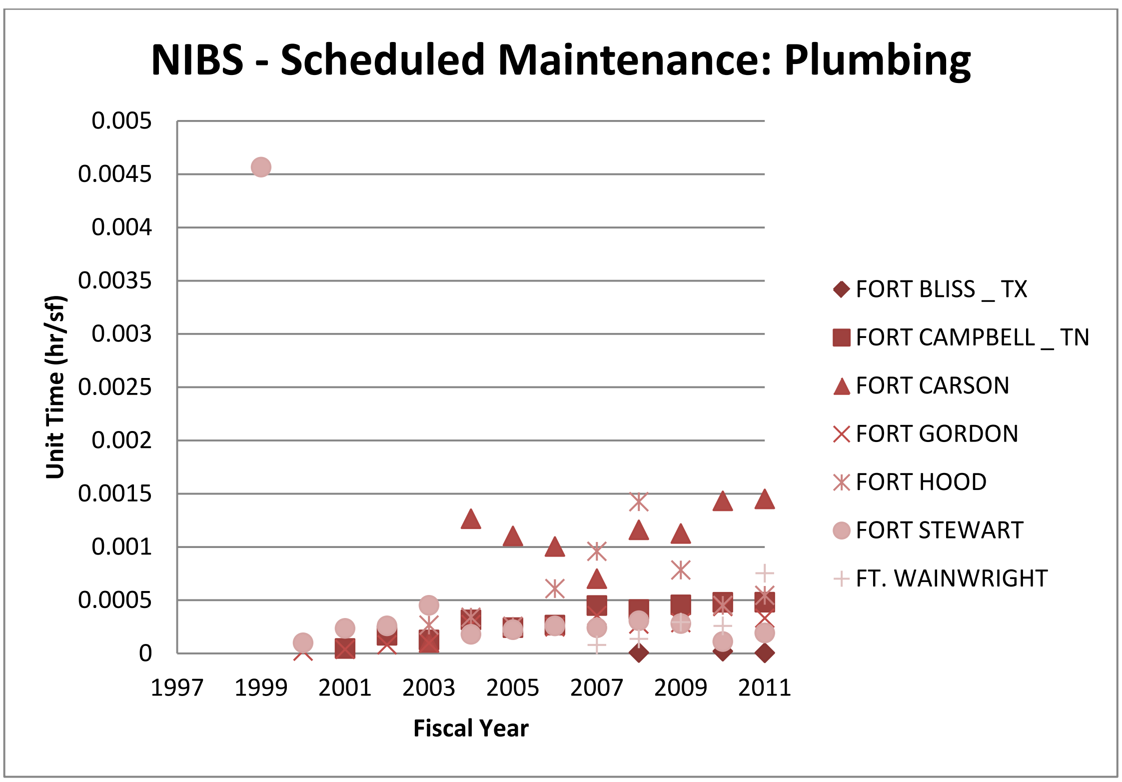

IBS - Scheduled Maintenance: HVAC
Unit Time (hr/sf)
0.0045
0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

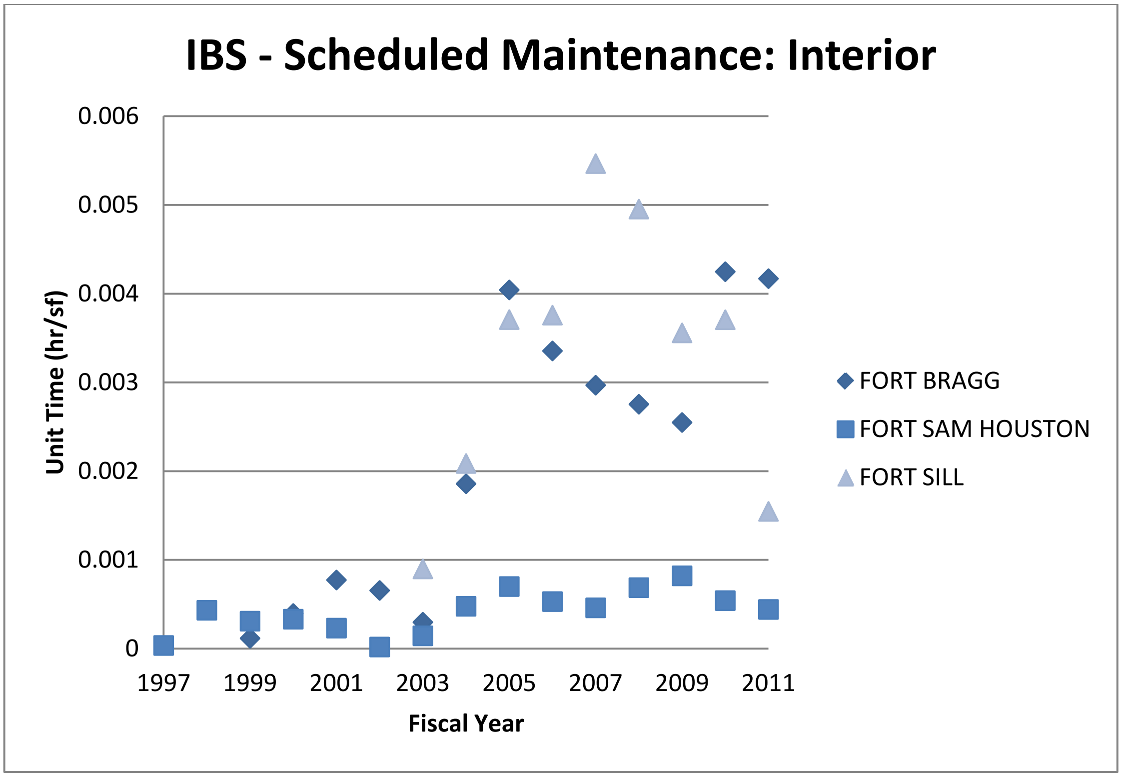

NIBS - Scheduled Maintenance: HVAC
Unit Time (hr/sf)
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT

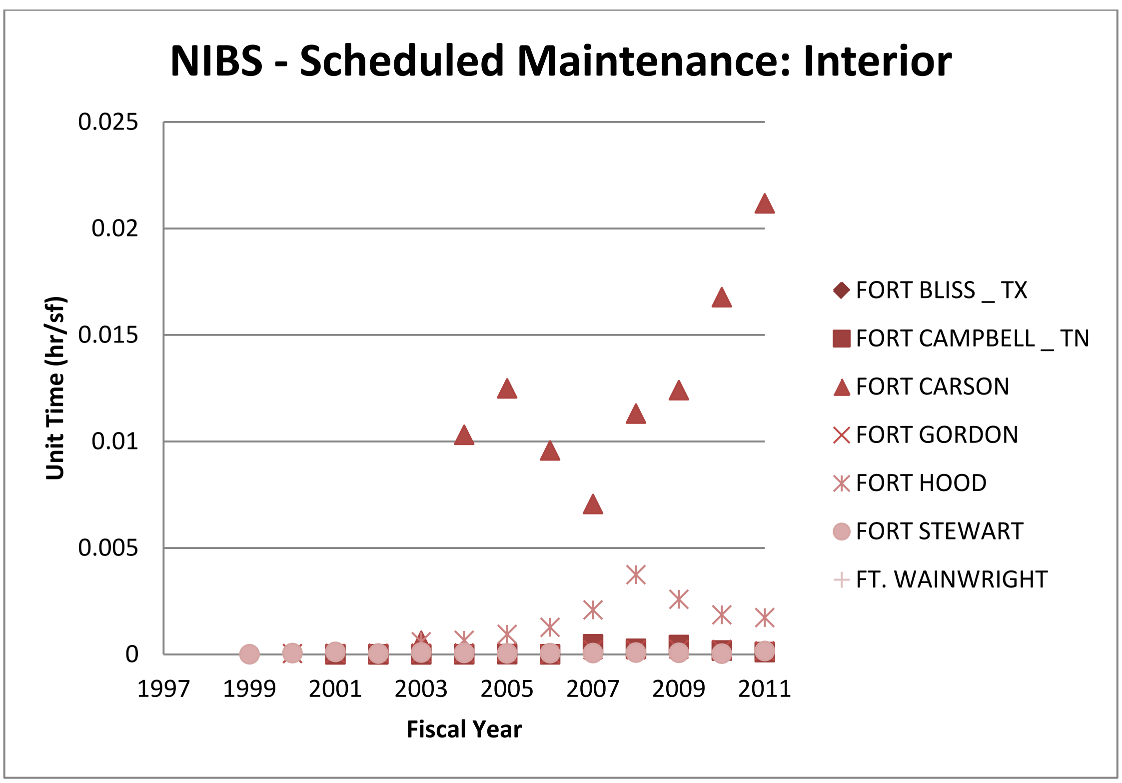

IBS - Scheduled Maintenance: Electrical
Unit Time (hr/sf)
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

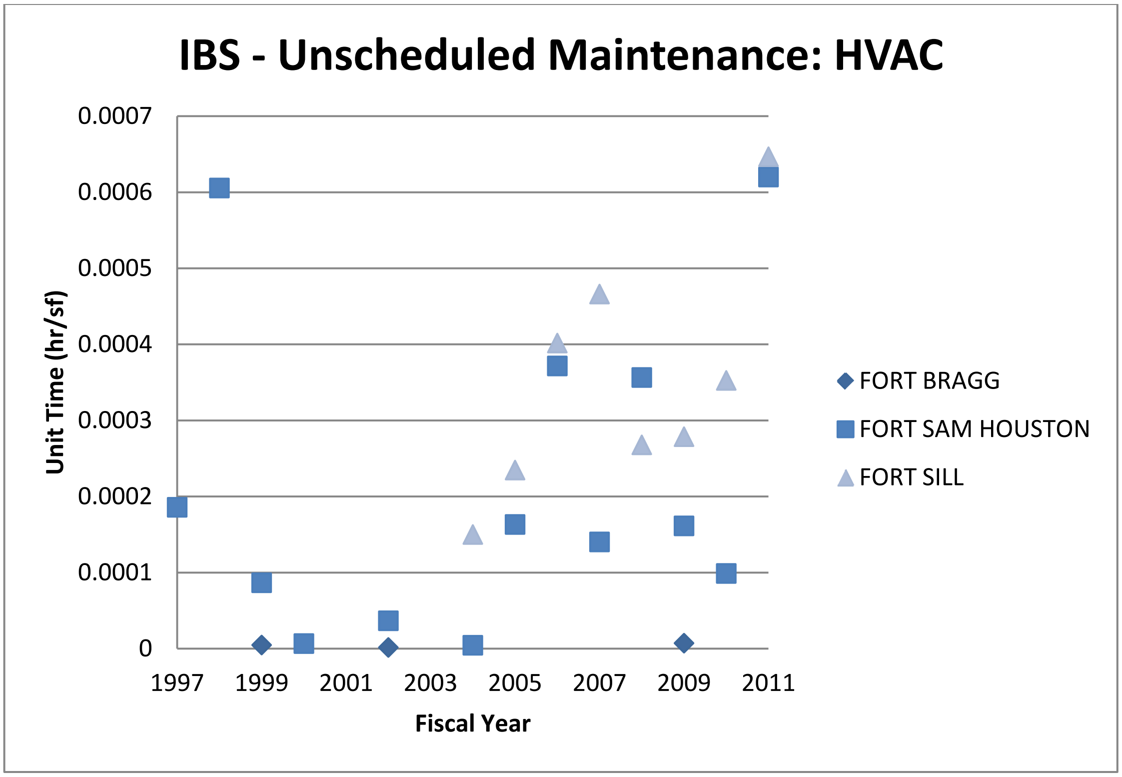

NIBS - Scheduled Maintenance: Electrical
Unit Time (hr/sf)
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT


IBS - Scheduled Maintenance: Plumbing
Unit Time (hr/sf)
0.0018
0.0016
0.0014
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
0
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

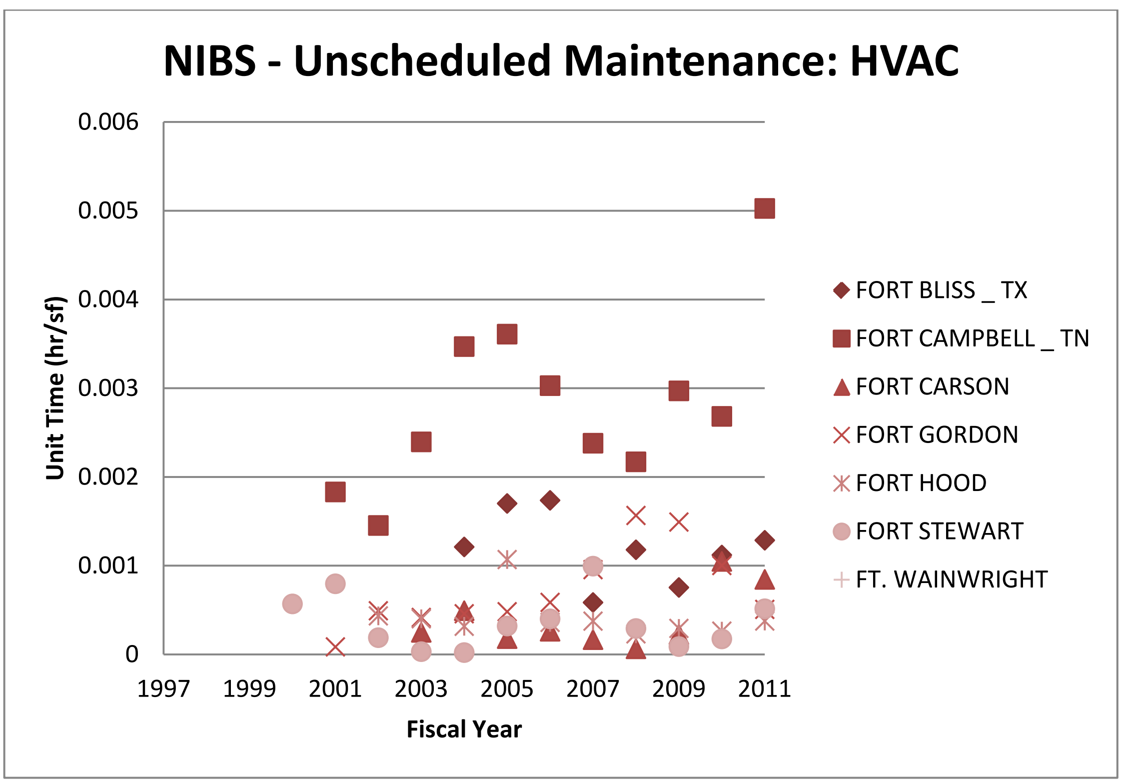

NIBS - Scheduled Maintenance: Plumbing
Unit Time (hr/sf)
0.005
0.0045
0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT


IBS - Scheduled Maintenance: Interior
Unit Time (hr/sf)
0.006
0.005
0.004
0.003
0.002
0.001
0
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

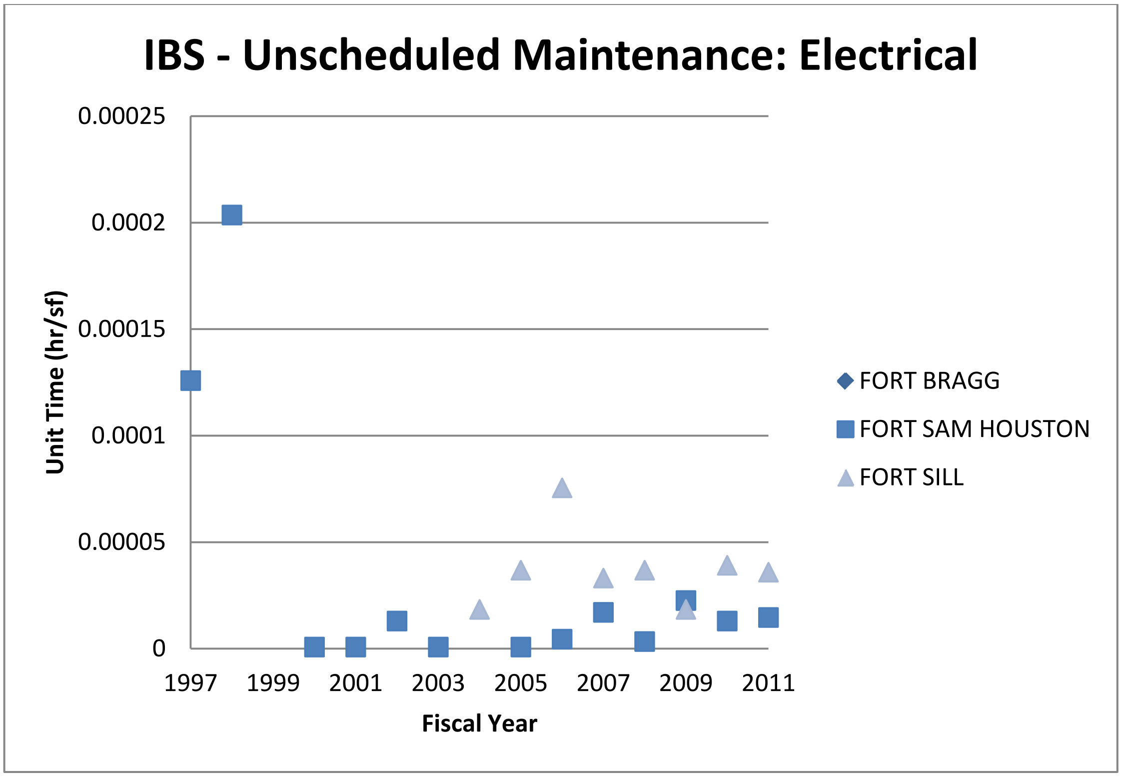

NIBS - Scheduled Maintenance: Interior
Unit Time (hr/sf)
0.025
0.02
0.015
0.01
0.005
0
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT

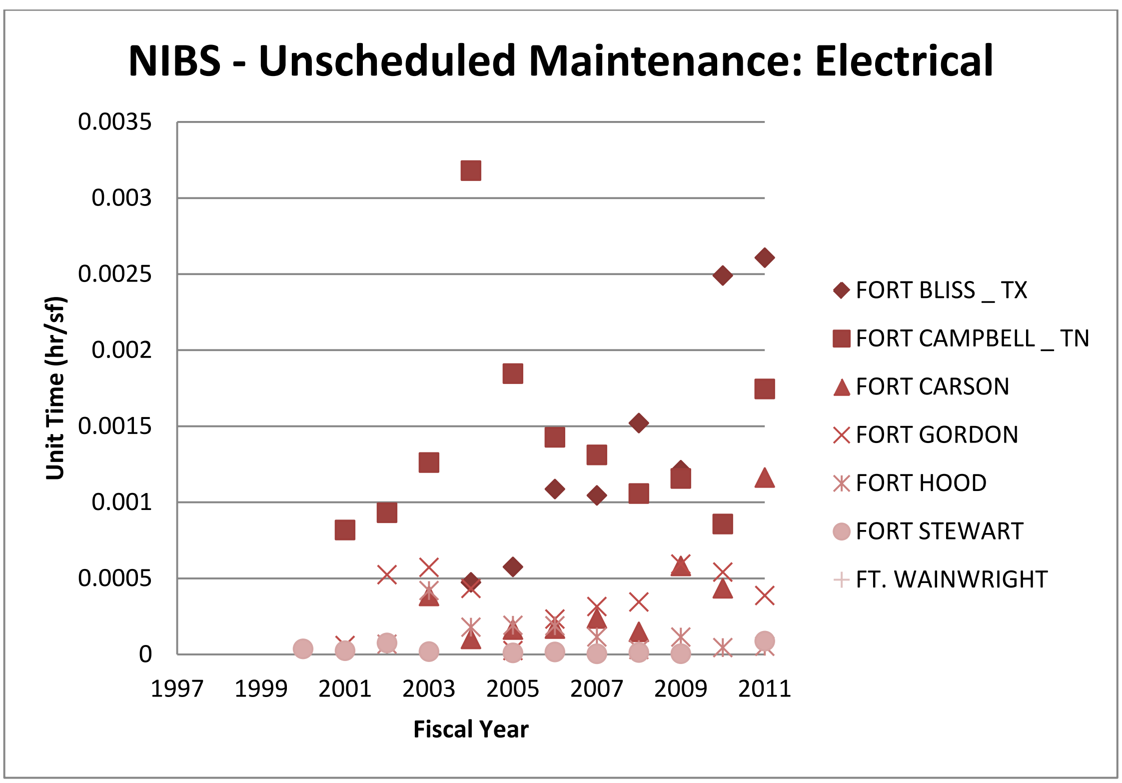


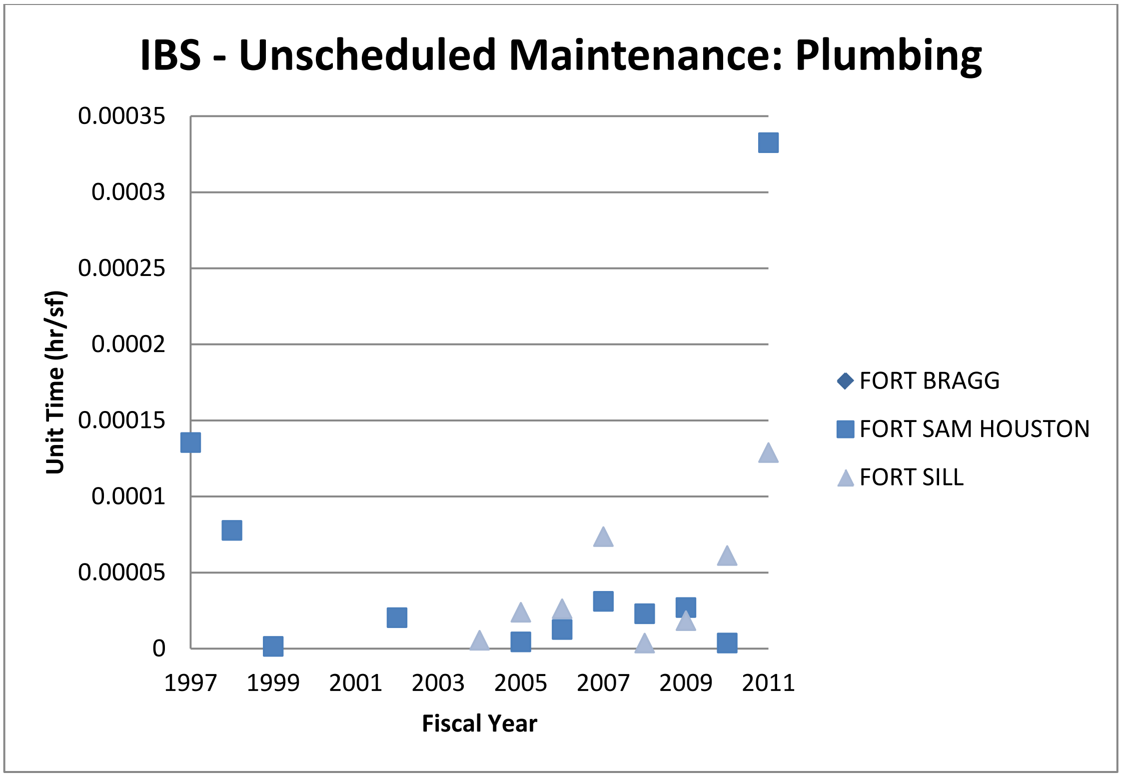
IBS - Unscheduled Maintenance: HVAC
Unit Time (hr/sf)
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

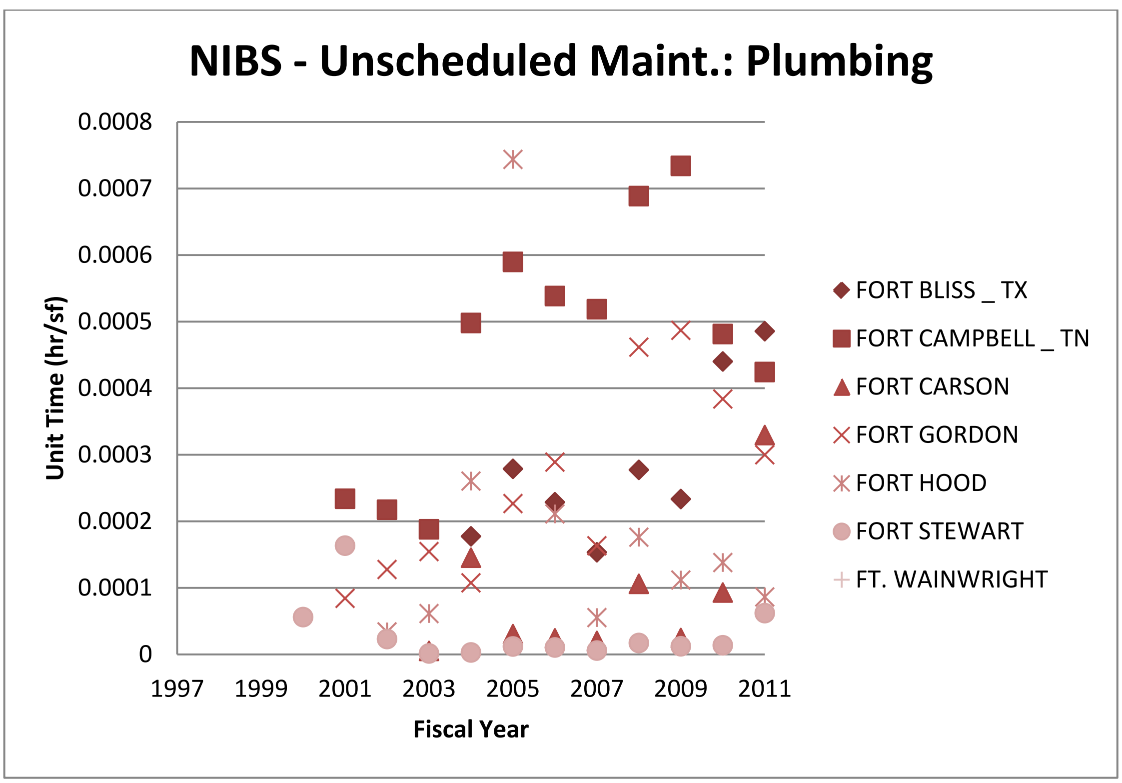


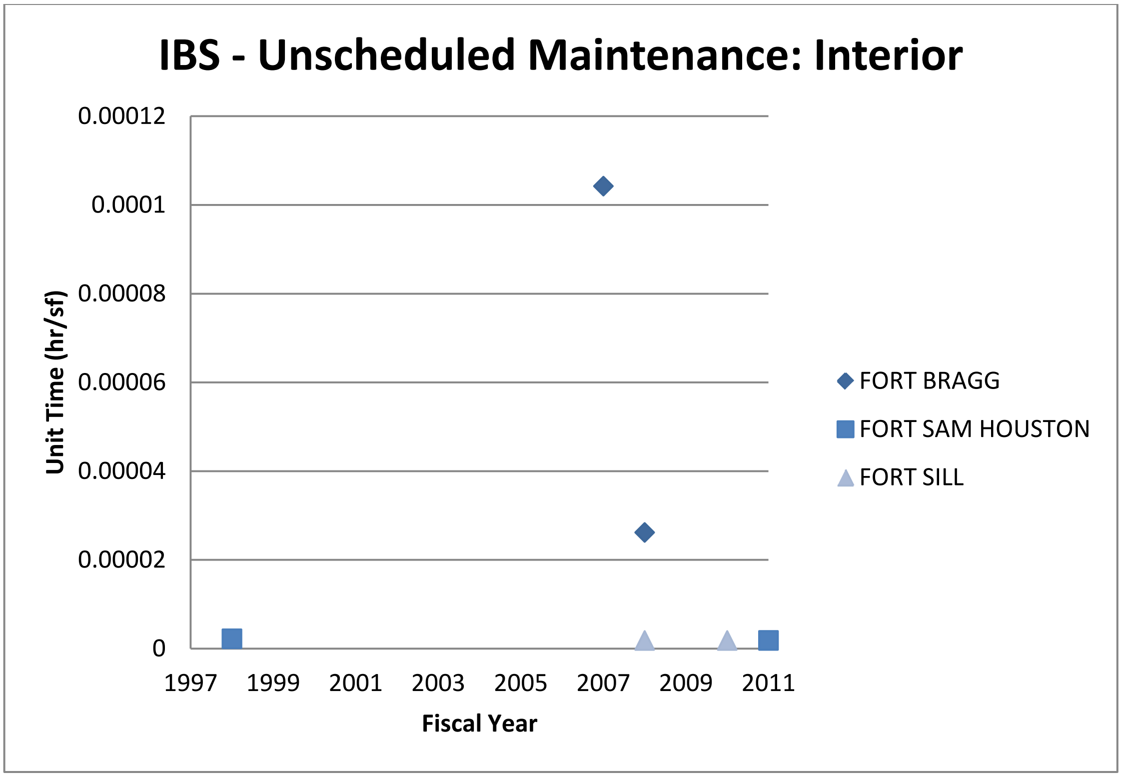
NIBS - Unscheduled Maintenance: HVAC
Unit Time (hr/sf)
0.006
0.005
0.004
0.003
0.002
0.001
0
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT

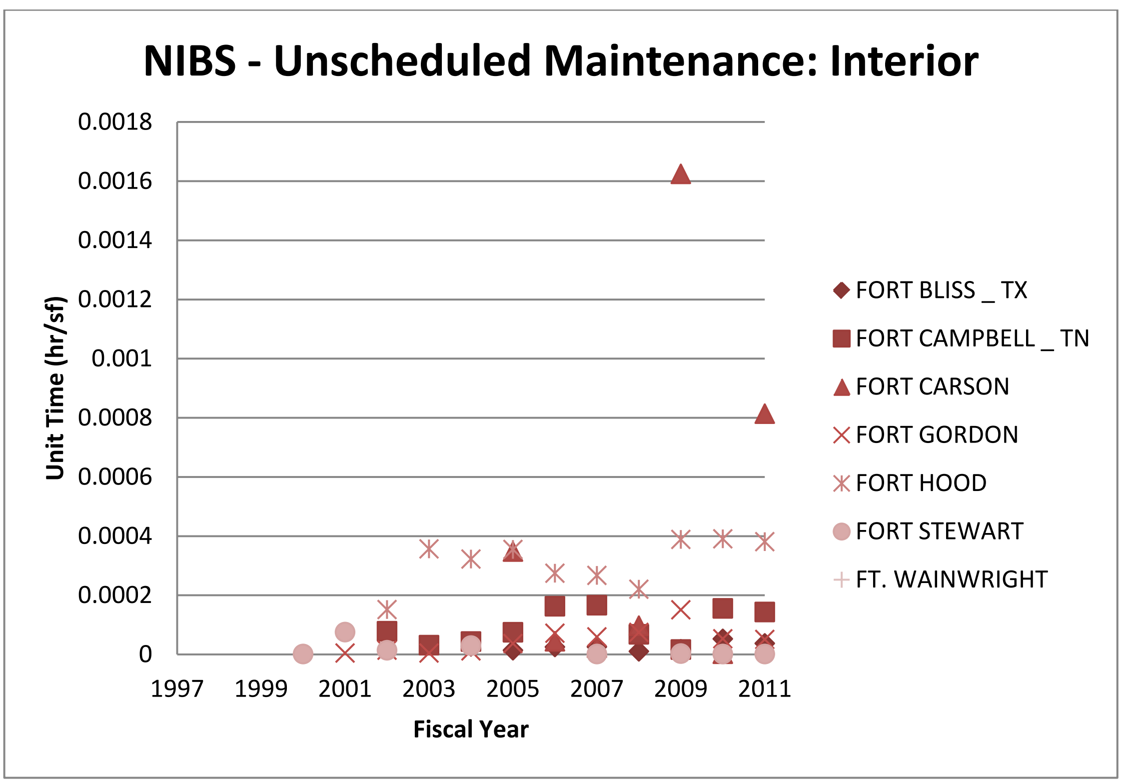

IBS - Unscheduled Maintenance: Electrical
0.00025
0.0002
0.00015
0.0001
0.00005
0
Unit Time (hr/sf)
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

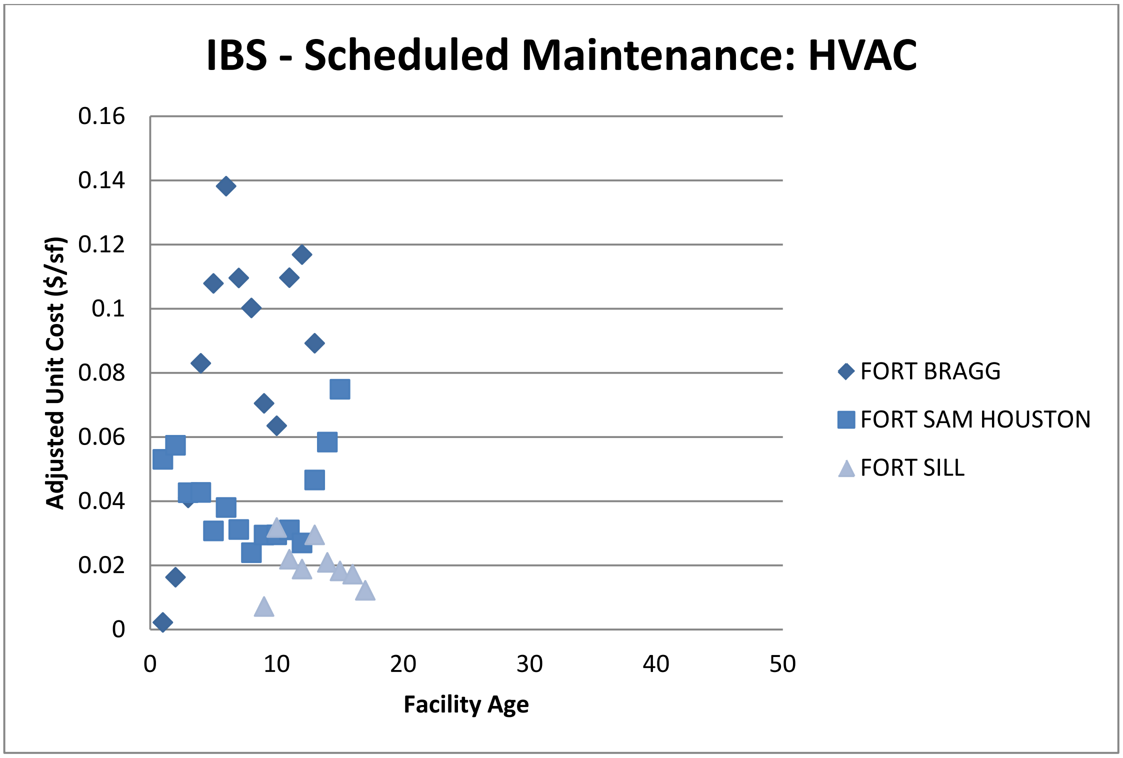

NIBS - Unscheduled Maintenance: Electrical
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
Unit Time (hr/sf)
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT

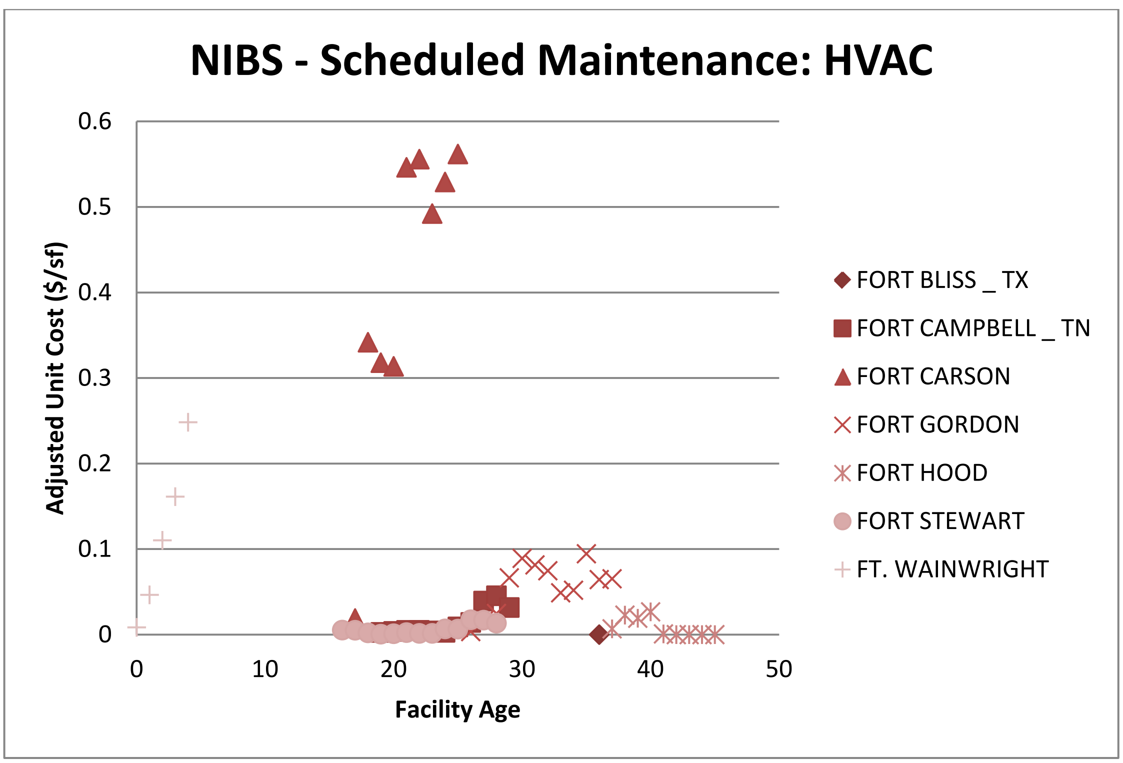

IBS - Unscheduled Maintenance: Plumbing
Unit Time (hr/sf)
0.00035
0.0003
0.00025
0.0002
0.00015
0.0001
0.00005
0
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

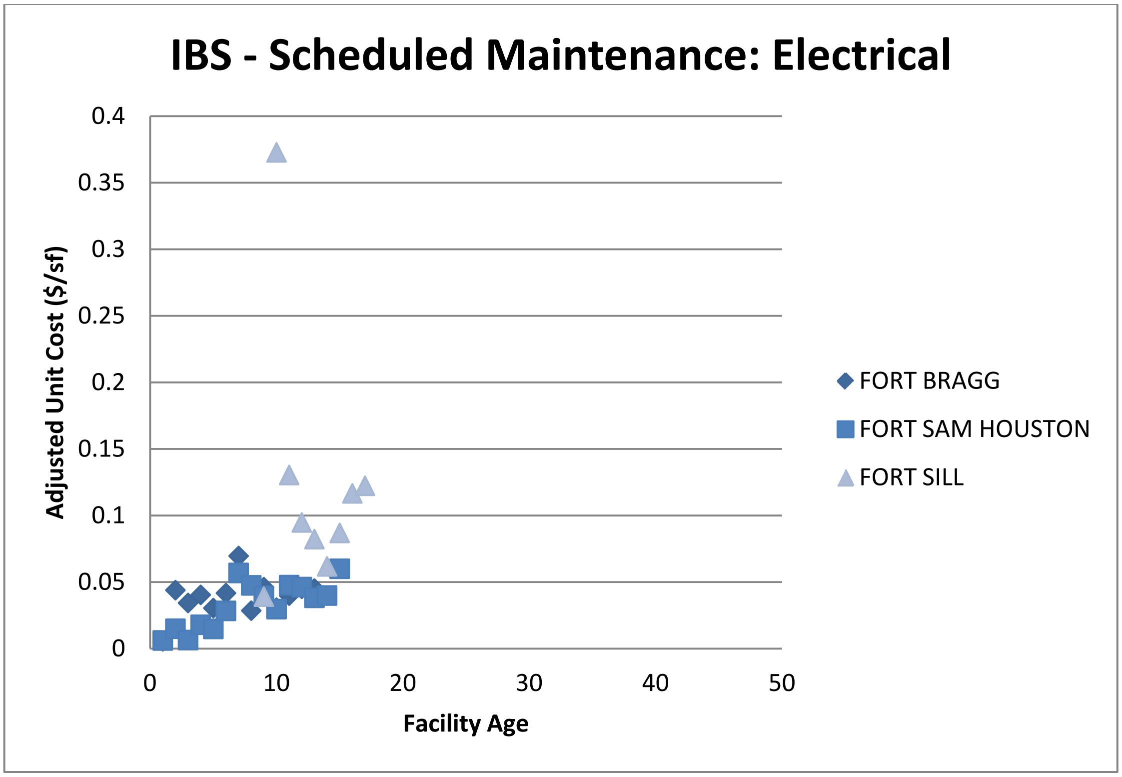

NIBS - Unscheduled Maint.: Plumbing
Unit Time (hr/sf)
0.0008
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT

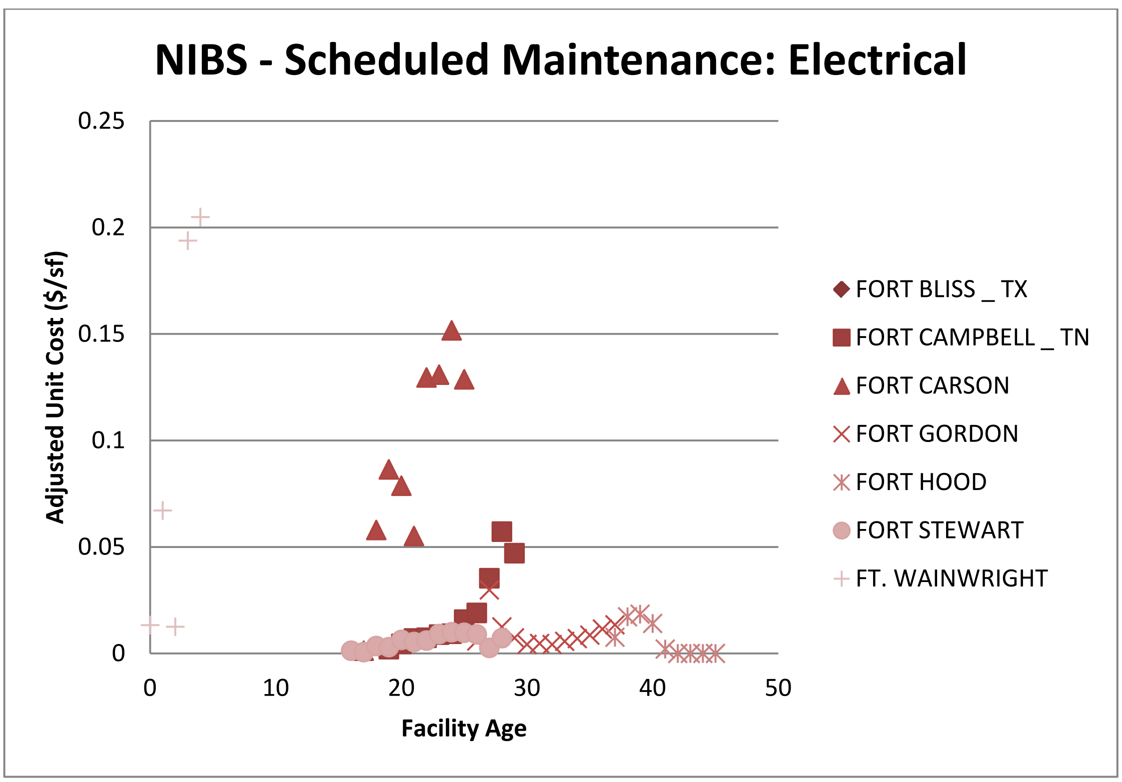

IBS - Unscheduled Maintenance: Interior
Unit Time (hr/sf)
0.00012
0.0001
0.00008
0.00006
0.00004
0.00002
0
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

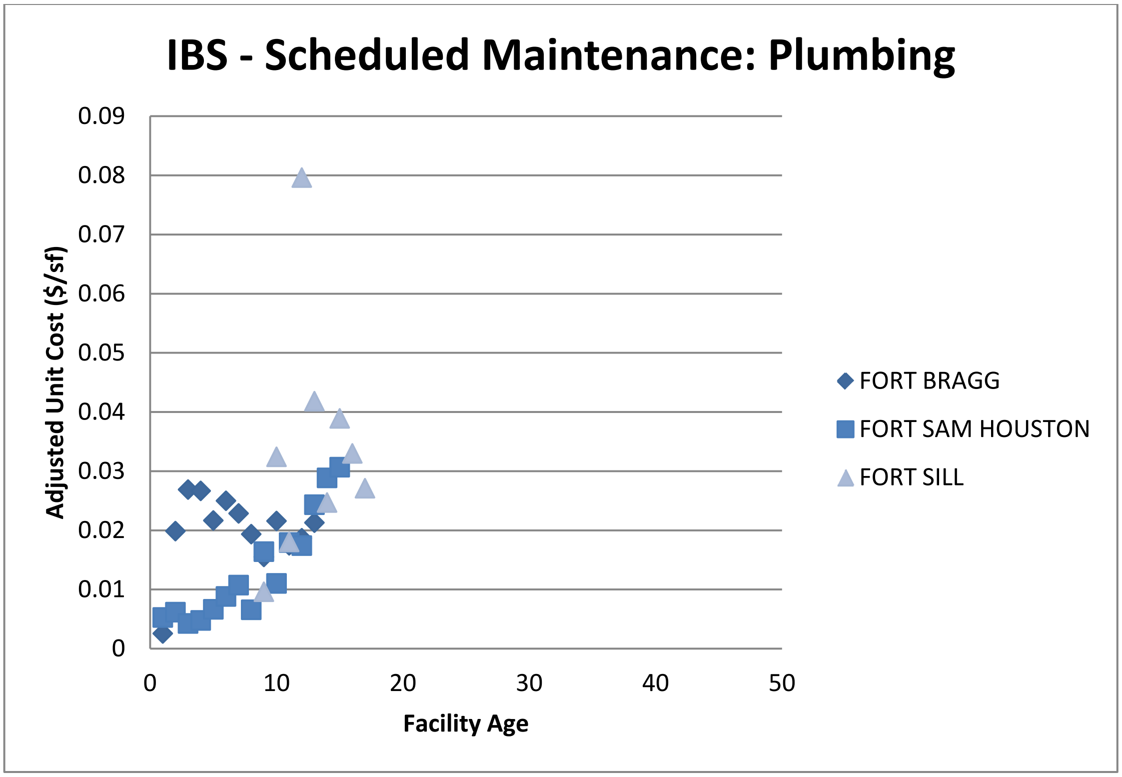

NIBS - Unscheduled Maintenance: Interior
Unit Time (hr/sf)
0.0018
0.0016
0.0014
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
0
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT

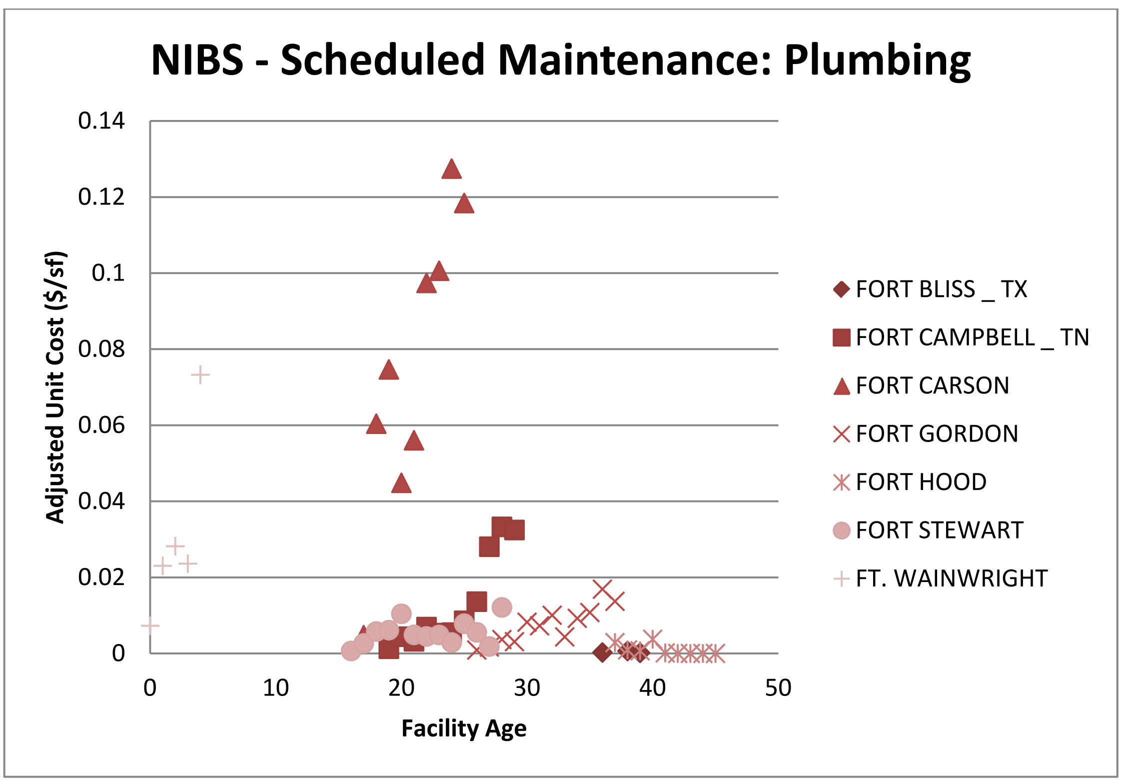

IBS - Scheduled Maintenance: HVAC
Adjusted Unit Cost ($/sf)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
10
20
30
40
50
Facility Age
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

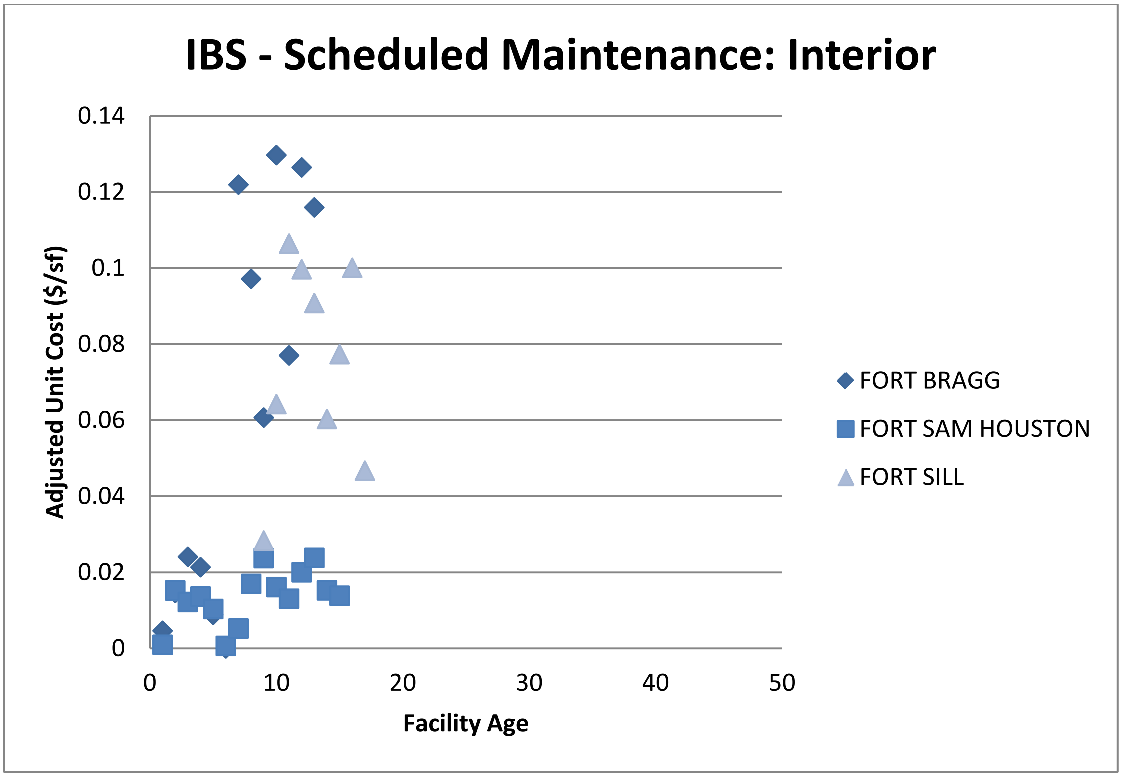

NIBS - Scheduled Maintenance: HVAC
Adjusted Unit Cost ($/sf)
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
Facility Age
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT

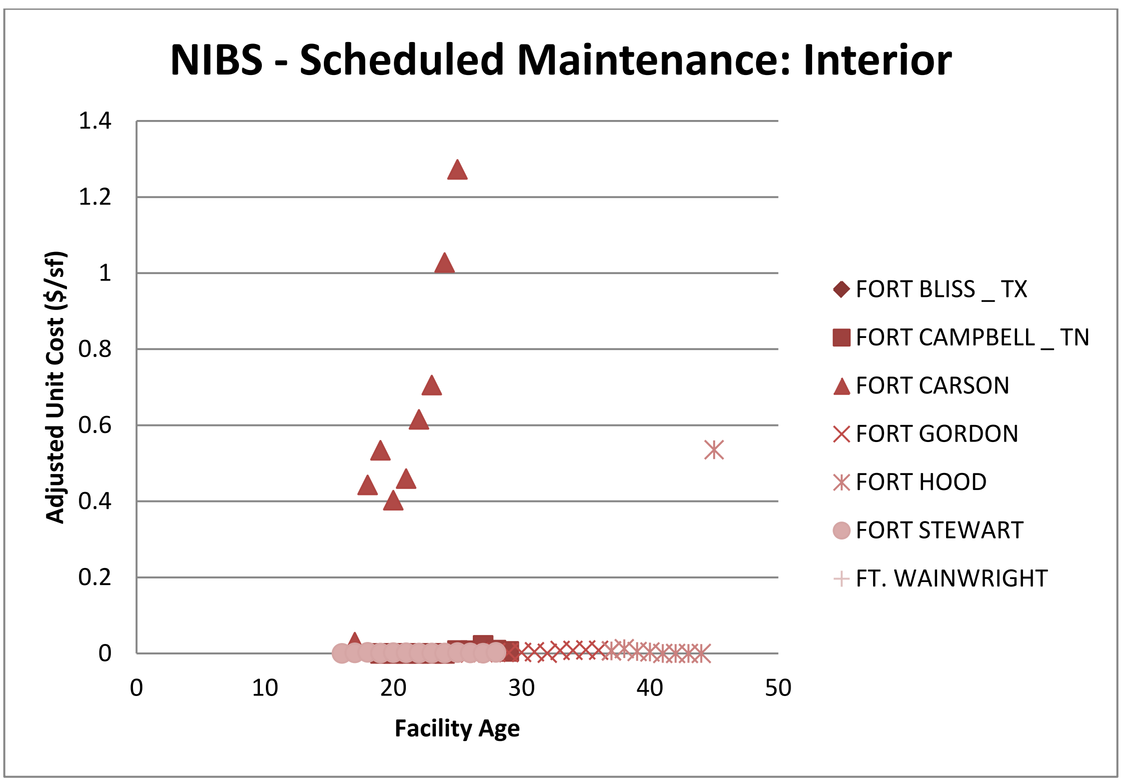

IBS - Scheduled Maintenance: Electrical
Adjusted Unit Cost ($/sf)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
10
20
30
40
50
Facility Age
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

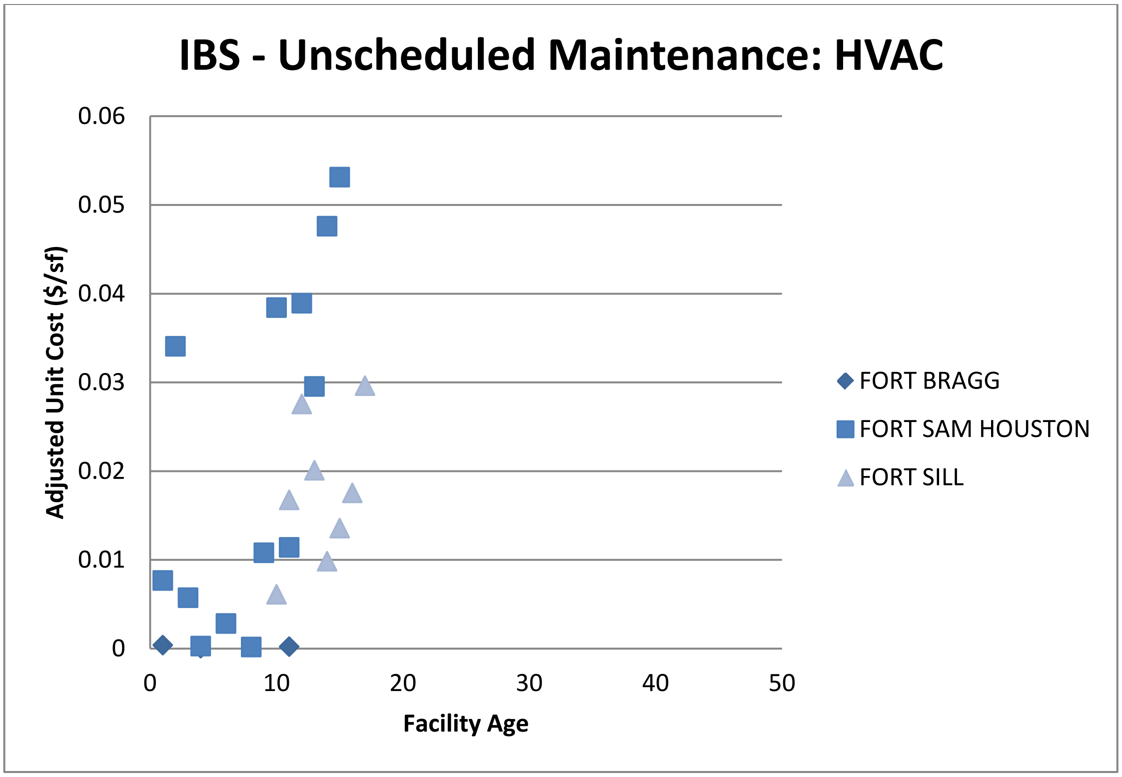

NIBS - Scheduled Maintenance: Electrical
Adjusted Unit Cost ($/sf)
0.25
0.2
0.15
0.1
0.05
0
0
10
20
30
40
50
Facility Age
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT

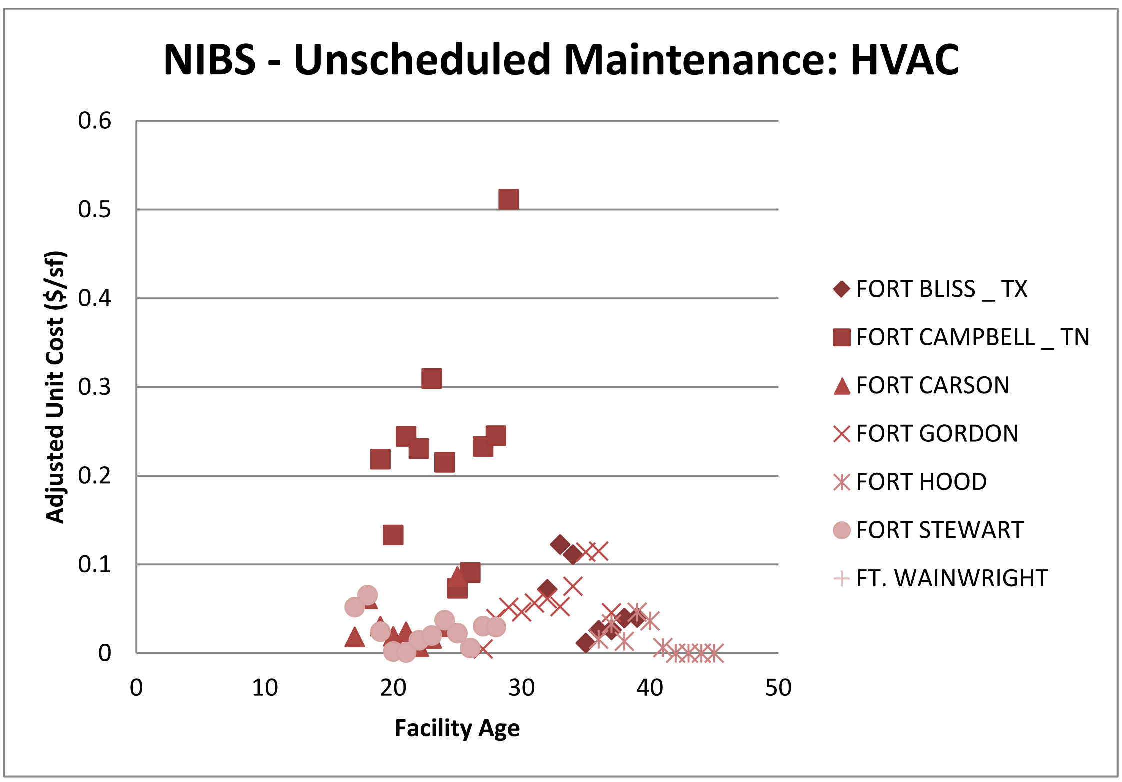

IBS - Scheduled Maintenance: Plumbing
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Adjusted Unit Cost ($/sf)
0
10
20
30
40
50
Facility Age
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

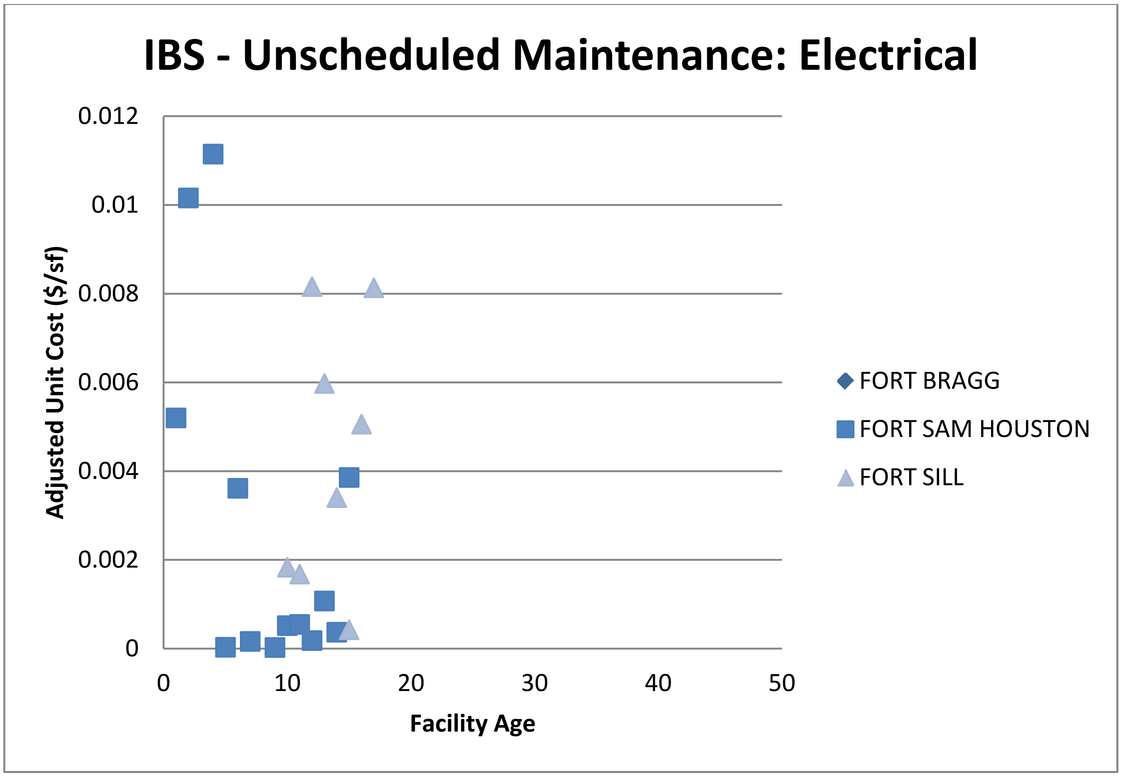

NIBS - Scheduled Maintenance: Plumbing
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Adjusted Unit Cost ($/sf)
0
10
20
30
40
50
Facility Age
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT

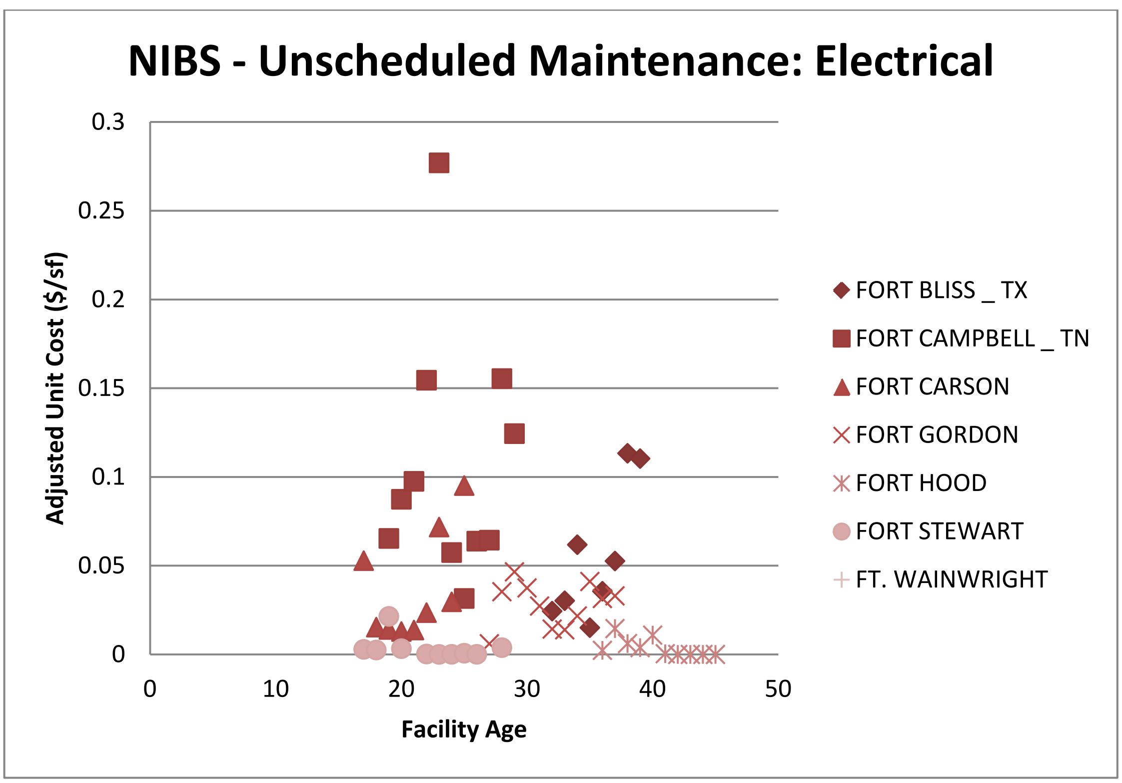

IBS - Scheduled Maintenance: Interior
Adjusted Unit Cost ($/sf)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
10
20
30
40
50
Facility Age
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

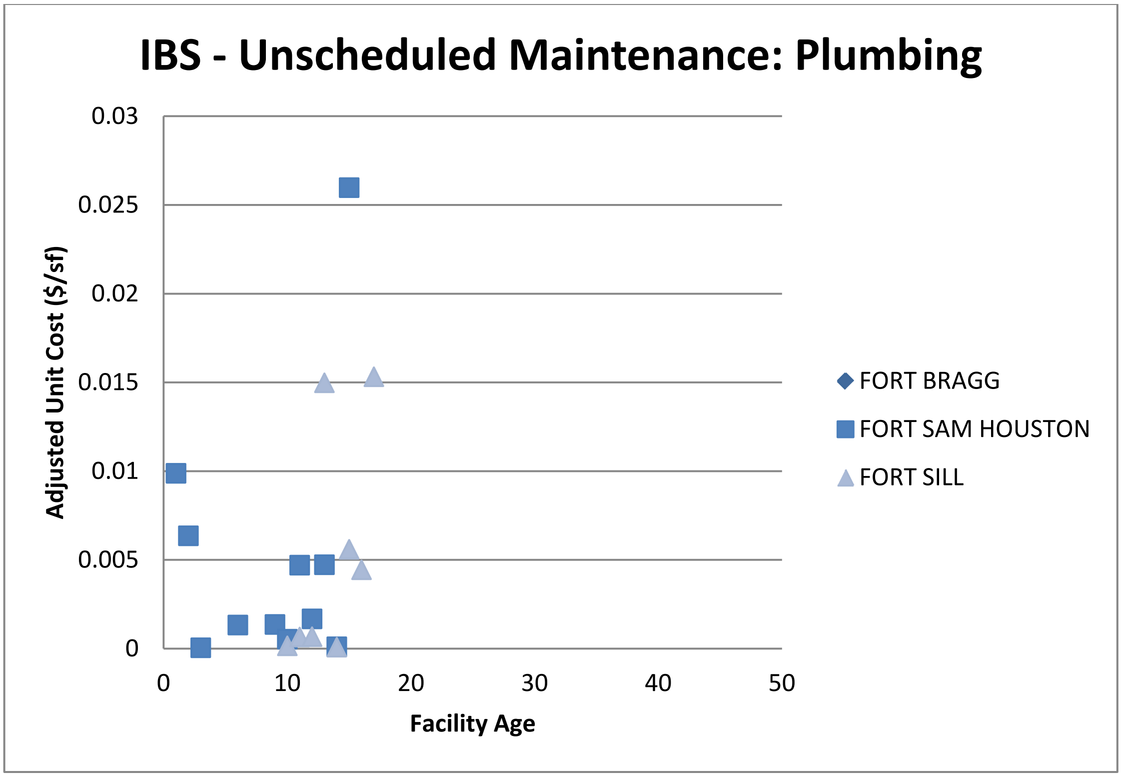

NIBS - Scheduled Maintenance: Interior
Adjusted Unit Cost ($/sf)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
10
20
30
40
50
Facility Age
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT

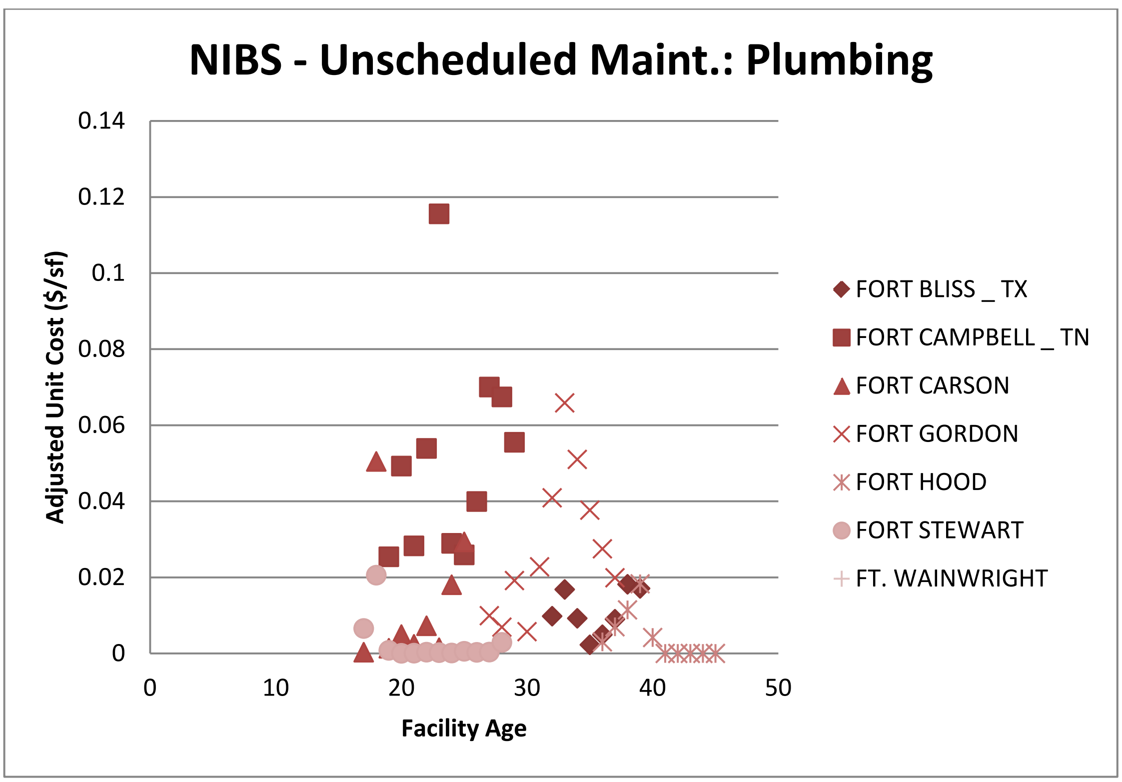

IBS - Unscheduled Maintenance: HVAC
0.06
0.05
0.04
0.03
0.02
0.01
0
Adjusted Unit Cost ($/sf)
0
10
20
30
40
50
Facility Age
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

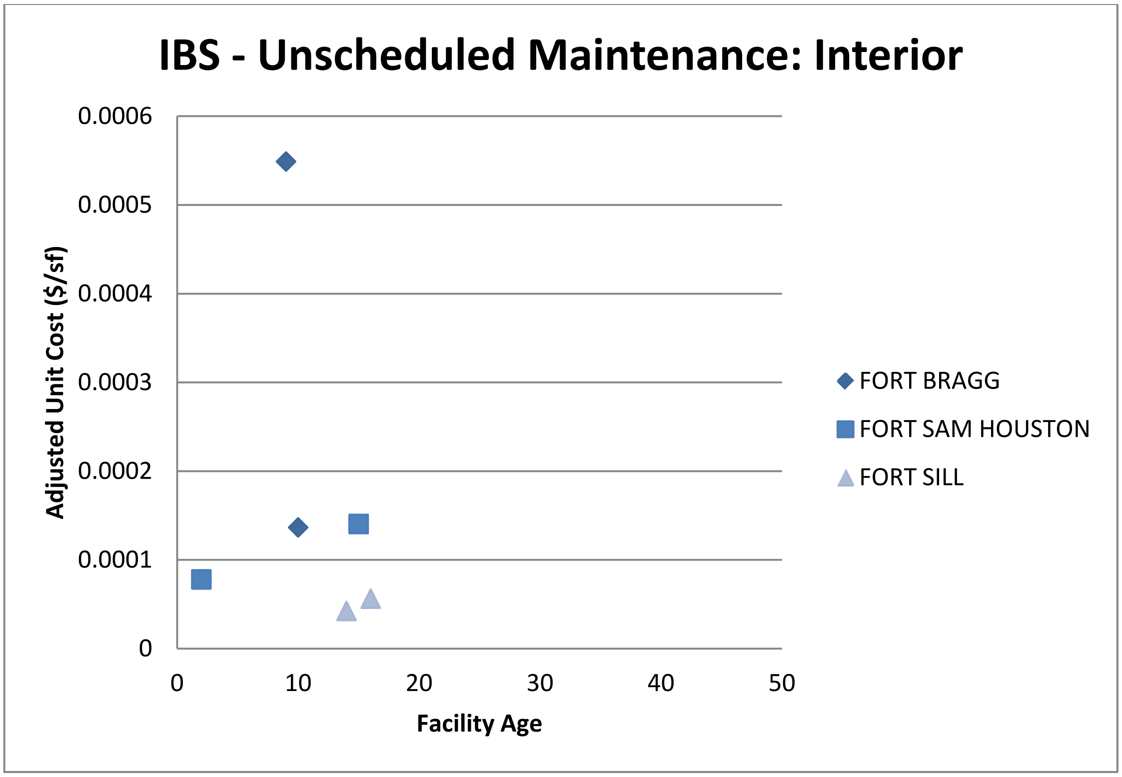

NIBS - Unscheduled Maintenance: HVAC
0.6
0.5
0.4
0.3
0.2
0.1
0
Adjusted Unit Cost ($/sf)
0
10
20
30
40
50
Facility Age
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT

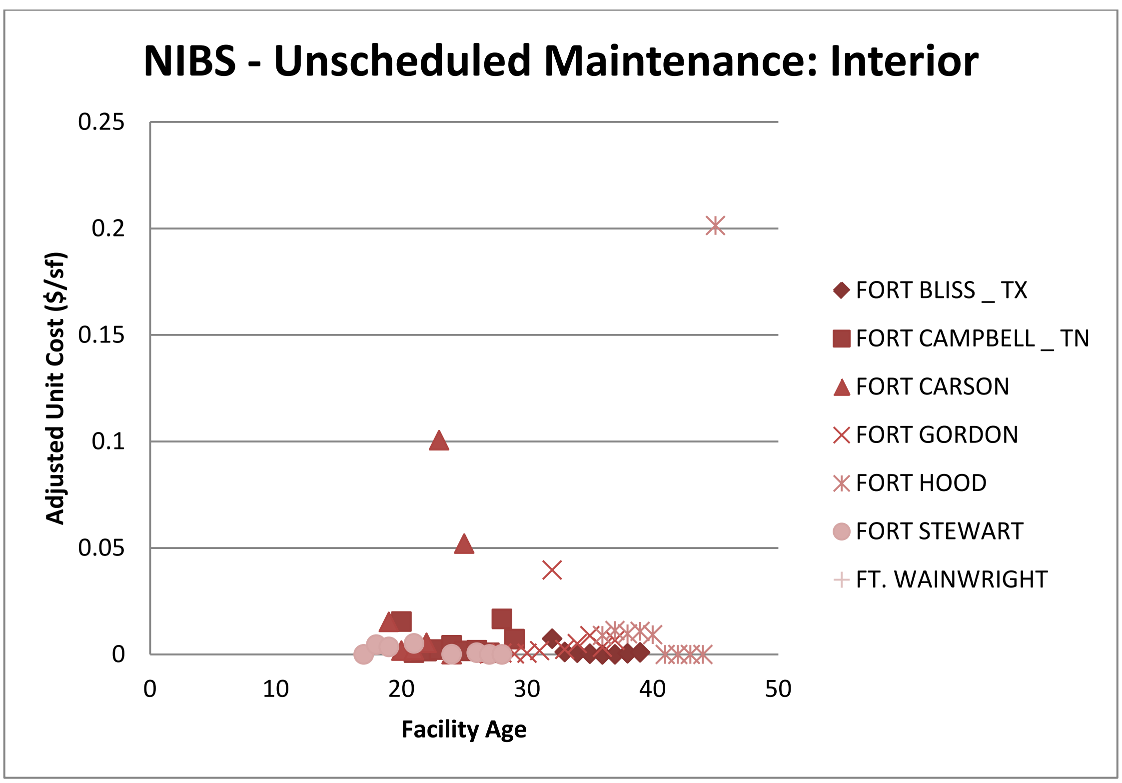

IBS - Unscheduled Maintenance: Electrical
Adjusted Unit Cost ($/sf)
0.012
0.01
0.008
0.006
0.004
0.002
0
0
10
20
30
40
50
Facility Age
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

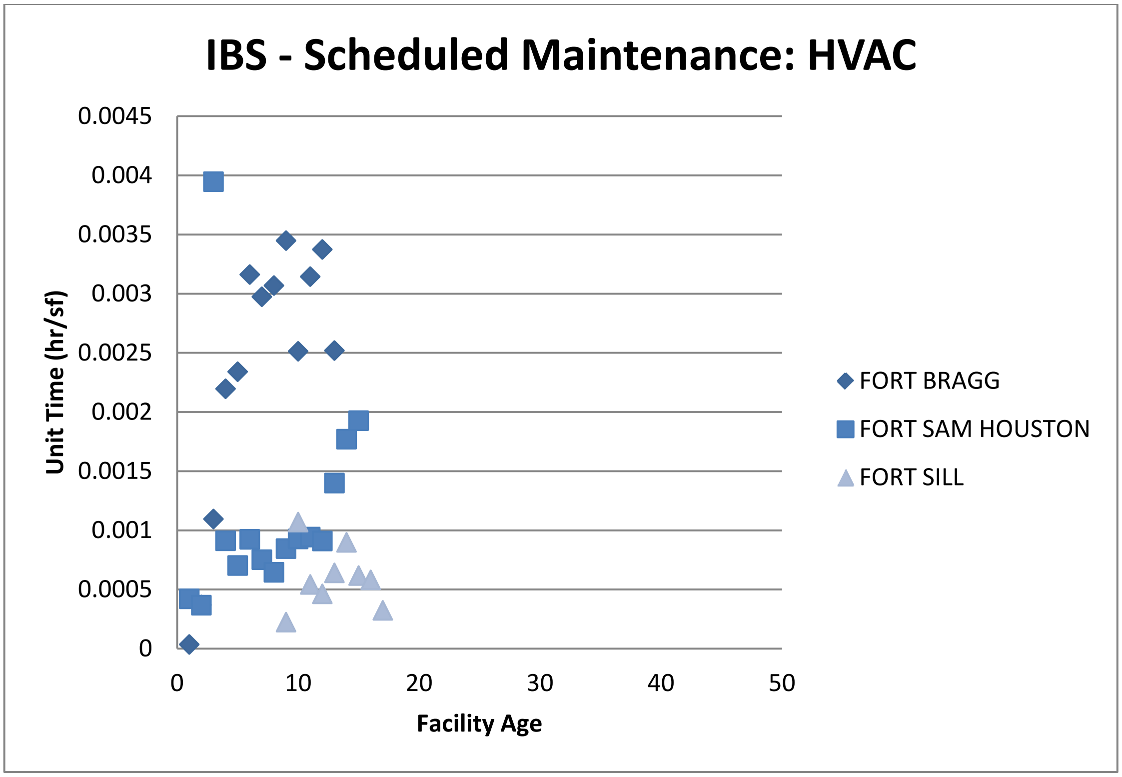

NIBS - Unscheduled Maintenance: Electrical
Adjusted Unit Cost ($/sf)
0.3
0.25
0.2
0.15
0.1
0.05
0
0
10
20
30
40
50
Facility Age
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT

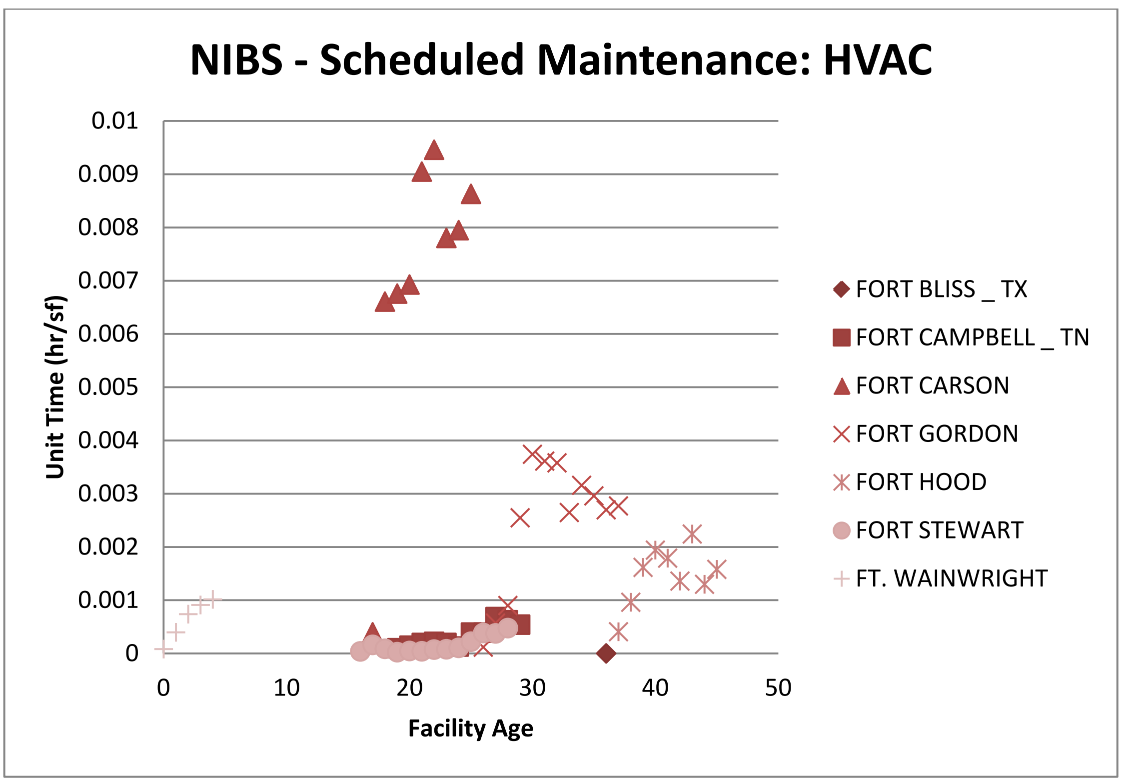

IBS - Unscheduled Maintenance: Plumbing
0.03
0.025
0.02
0.015
0.01
0.005
0
0
10
20
30
40
50
Facility Age
Adjusted Unit Cost ($/sf)
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

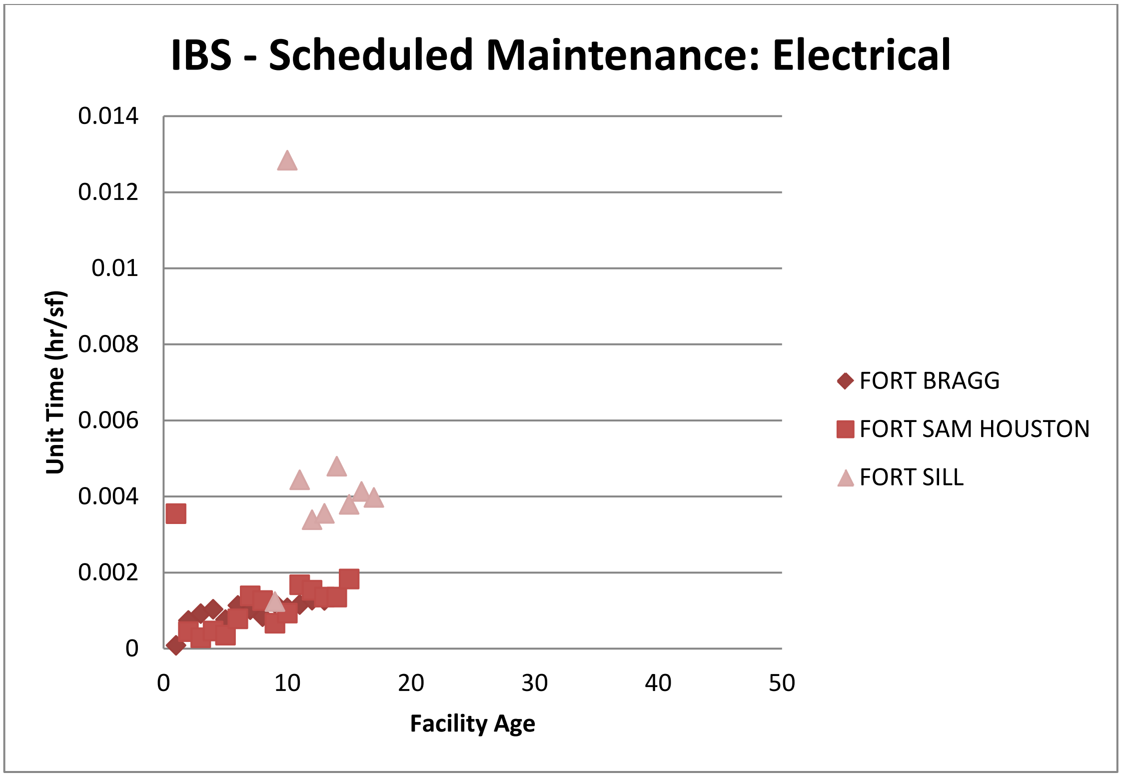

NIBS - Unscheduled Maint.: Plumbing
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
10
20
30
40
50
Facility Age
Adjusted Unit Cost ($/sf)
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT

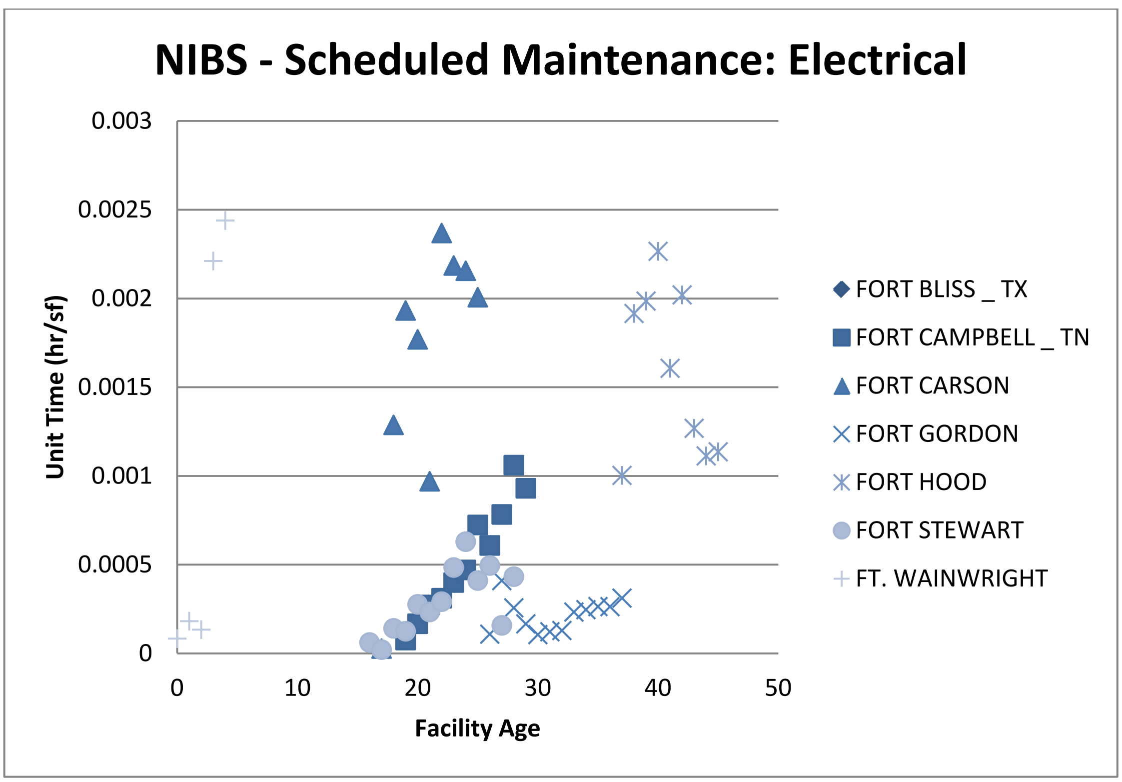

IBS - Unscheduled Maintenance: Interior
Adjusted Unit Cost ($/sf)
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0
0
10
20
30
40
50
Facility Age
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

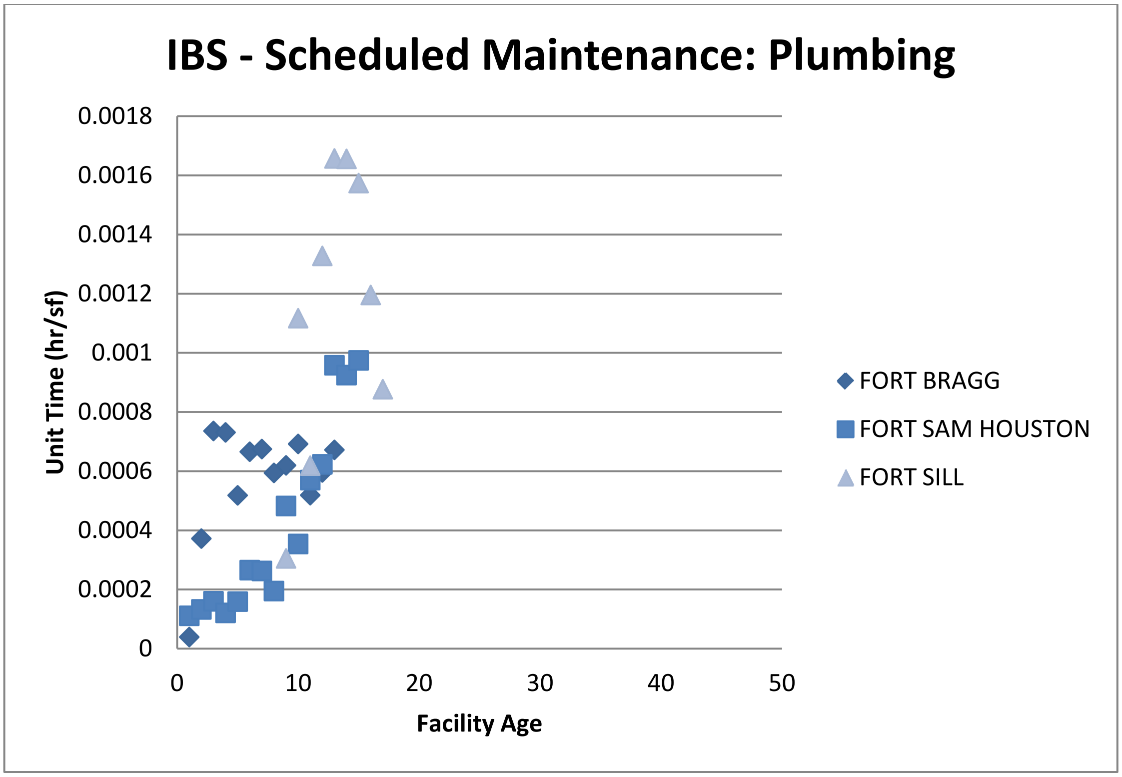

NIBS - Unscheduled Maintenance: Interior
Adjusted Unit Cost ($/sf)
0.25
0.2
0.15
0.1
0.05
0
0
10
20
30
40
50
Facility Age
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT

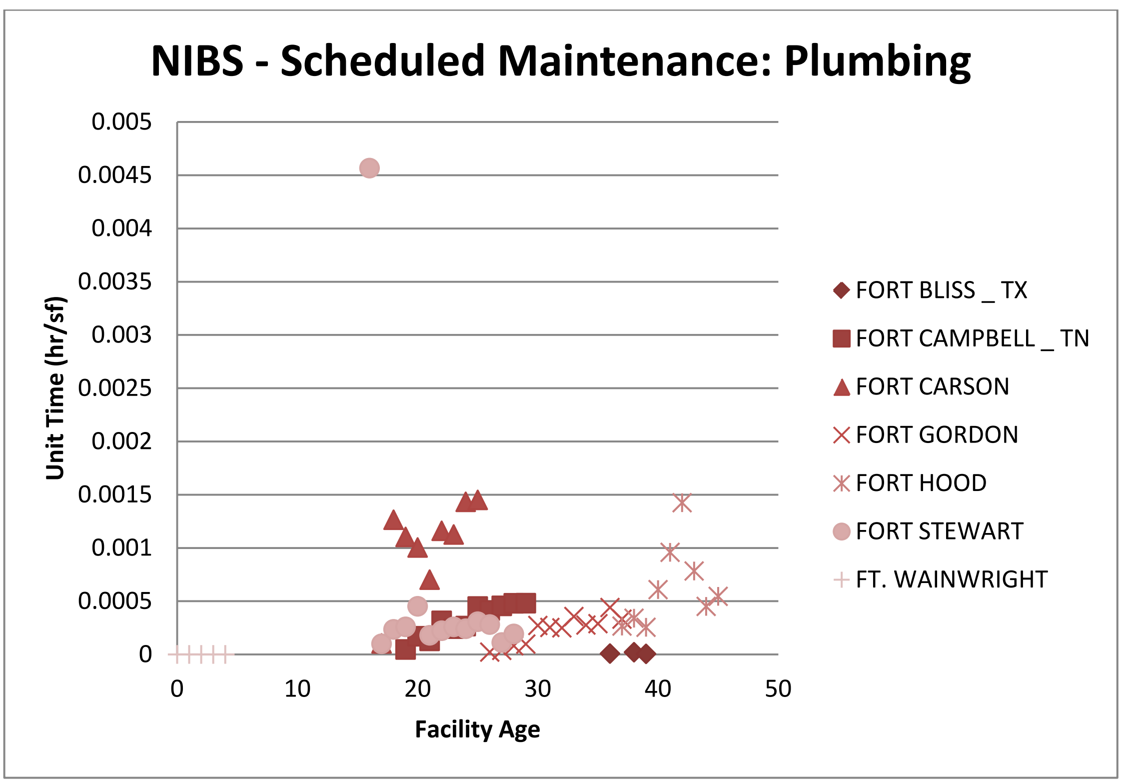

IBS - Scheduled Maintenance: HVAC
Unit Time (hr/sf)
0
0.0005
0.001
0.0015
0.002
0.0025
0.003
0.0035
0.004
0.0045
0
10
20
30
40
50
Facility Age
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

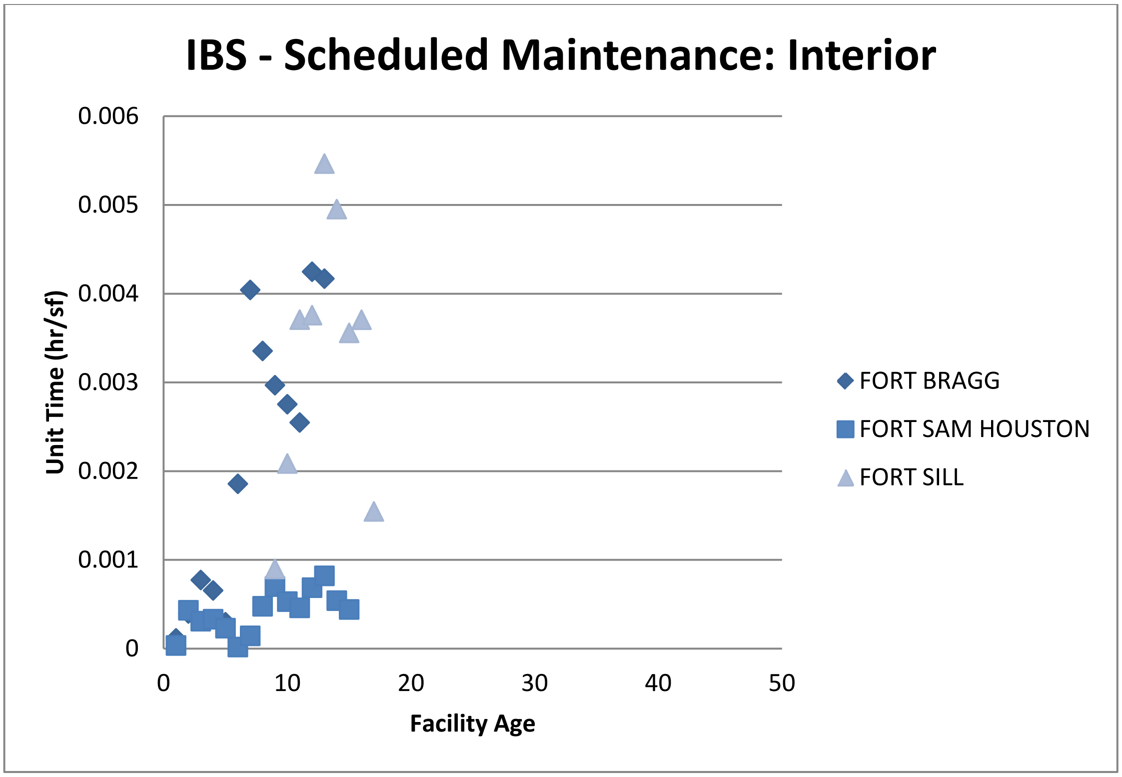

NIBS - Scheduled Maintenance: HVAC
Unit Time (hr/sf)
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
0.01
0
10
20
30
40
50
Facility Age
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT

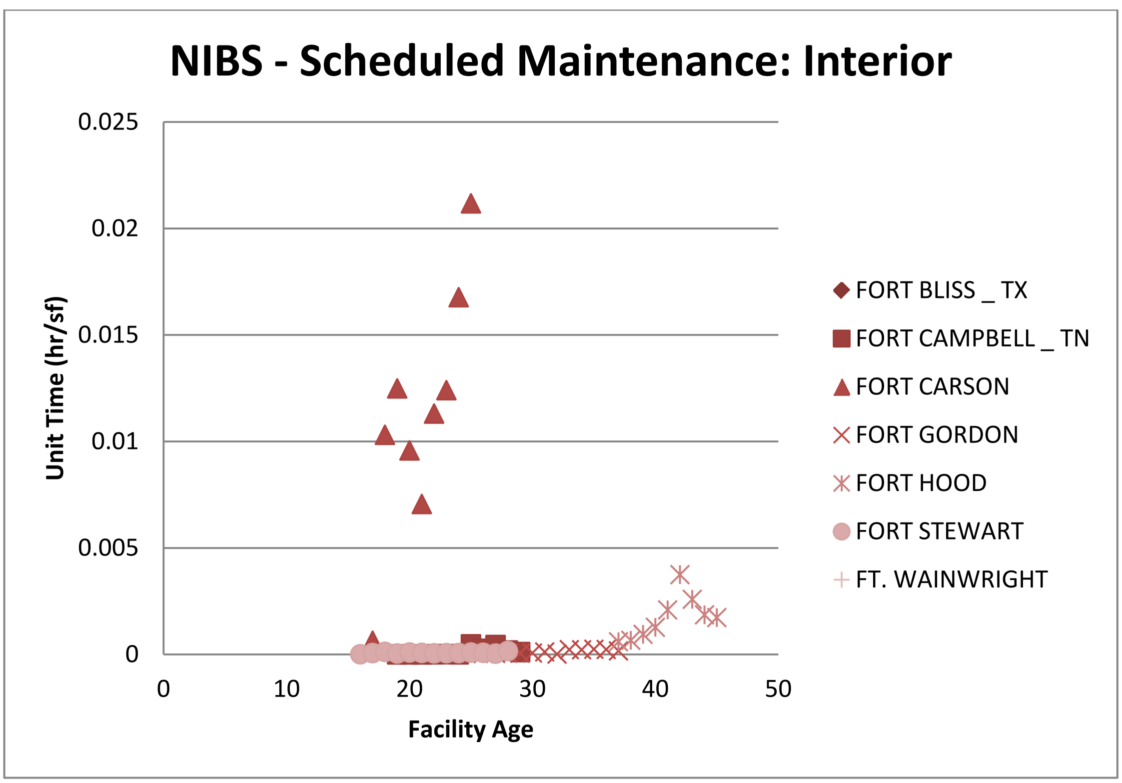

IBS - Scheduled Maintenance: Electrical
Unit Time (hr/sf)
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
10
20
30
40
50
Facility Age
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

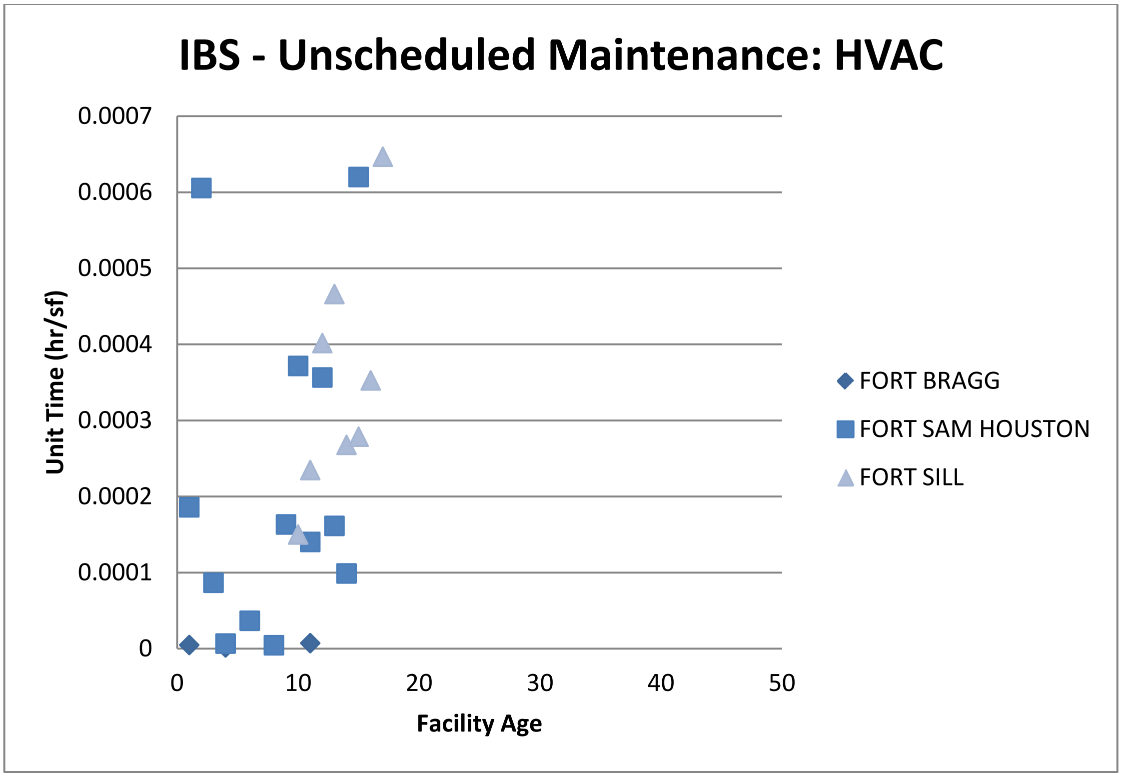

NIBS - Scheduled Maintenance: Electrical
Unit Time (hr/sf)
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
0
10
20
30
40
50
Facility Age
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT

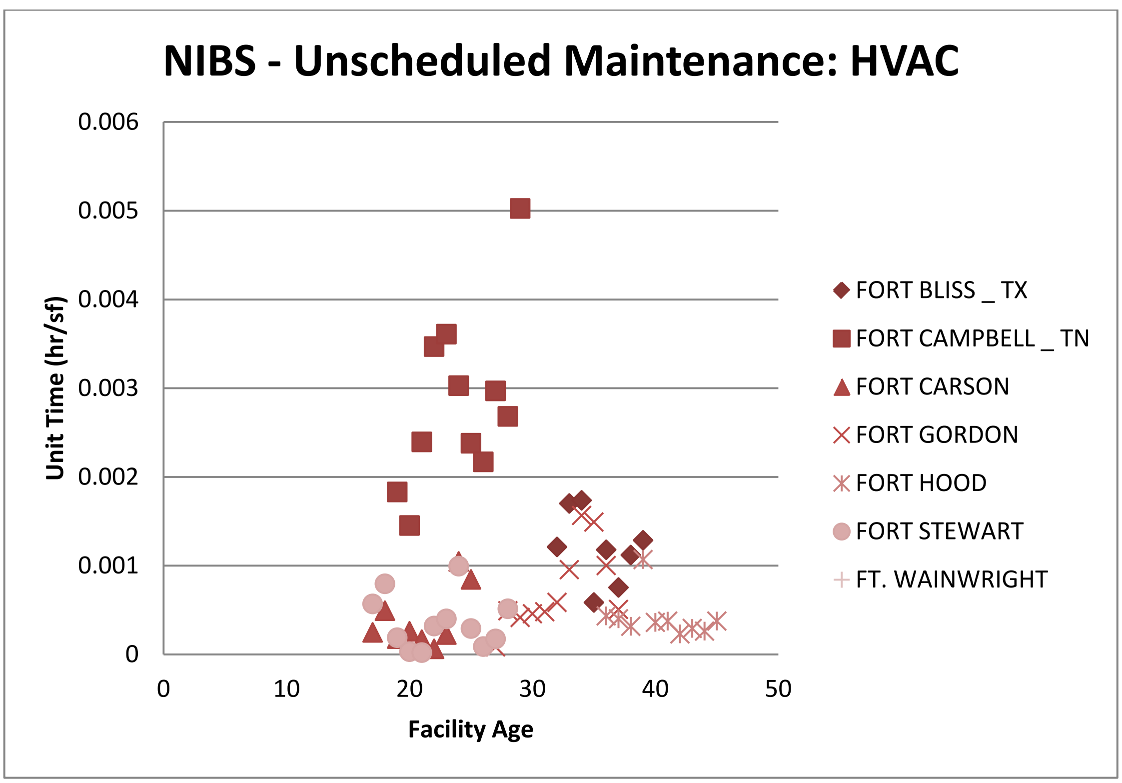

IBS - Scheduled Maintenance: Plumbing
Unit Time (hr/sf)
0.0018
0.0016
0.0014
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
0
0
10
20
30
40
50
Facility Age
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

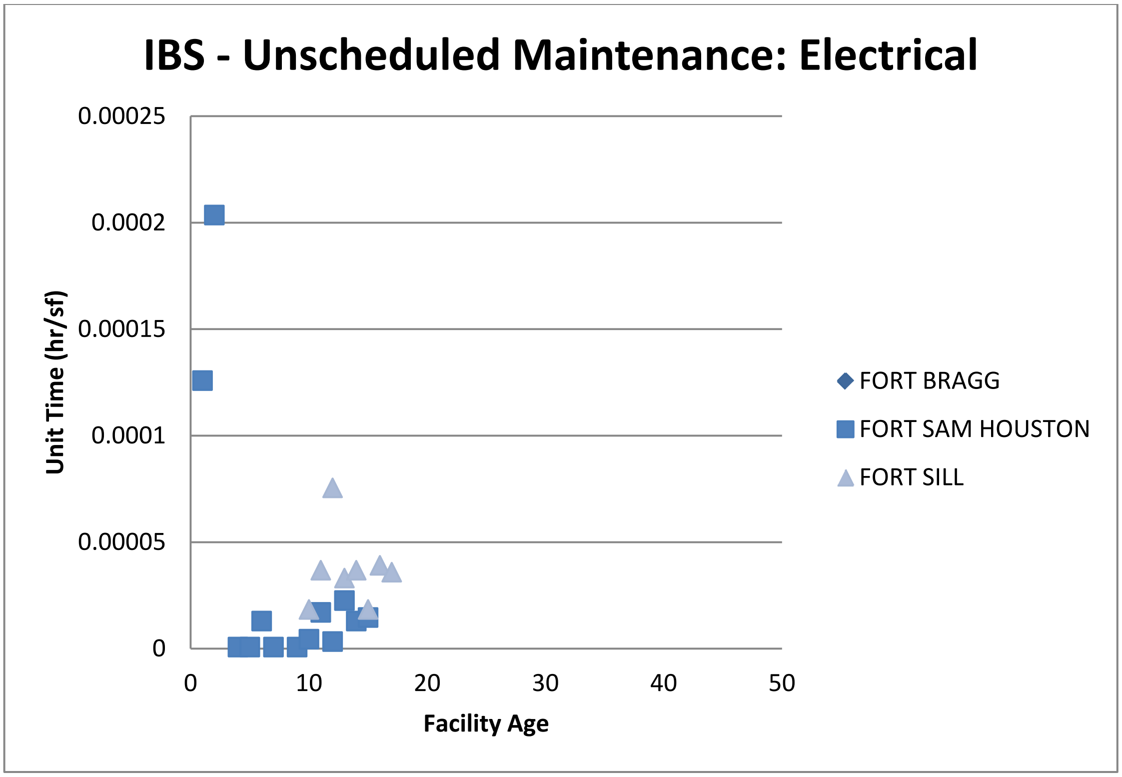

NIBS - Scheduled Maintenance: Plumbing
Unit Time (hr/sf)
0.005
0.0045
0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
0
10
20
30
40
50
Facility Age
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT

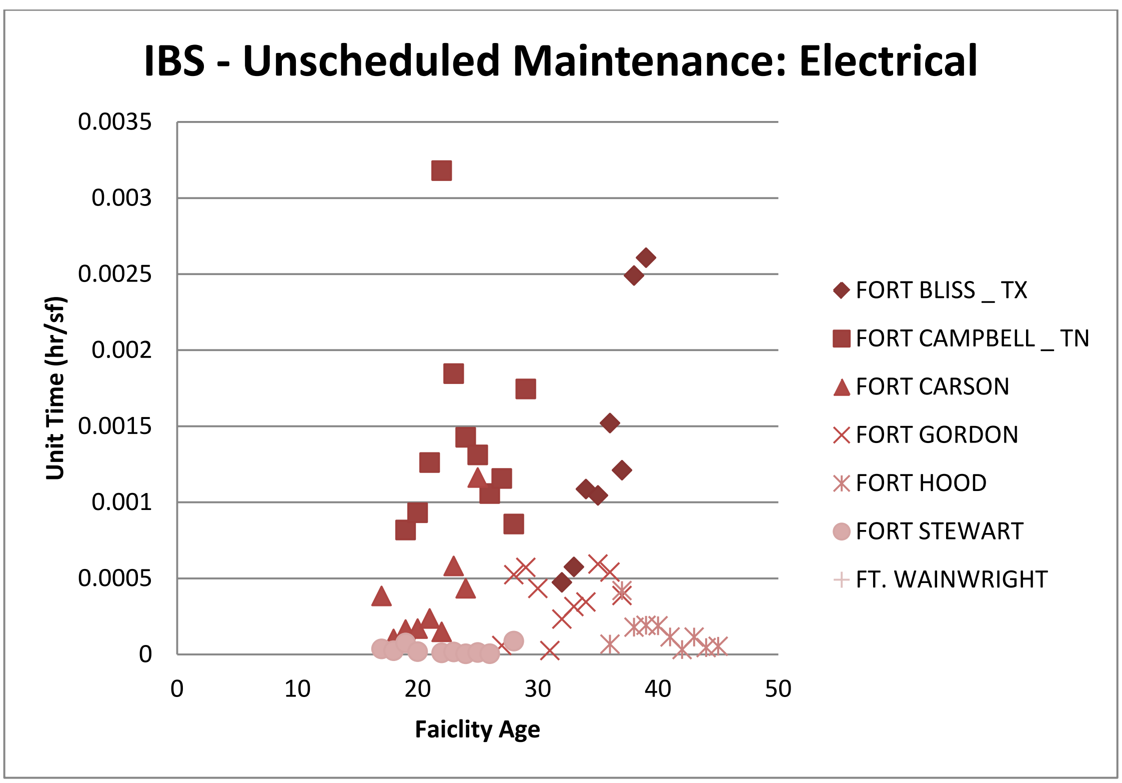

IBS - Scheduled Maintenance: Interior
0.006
0.005
0.004
0.003
0.002
0.001
0
Unit Time (hr/sf)
0
10
20
30
40
50
Facility Age
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

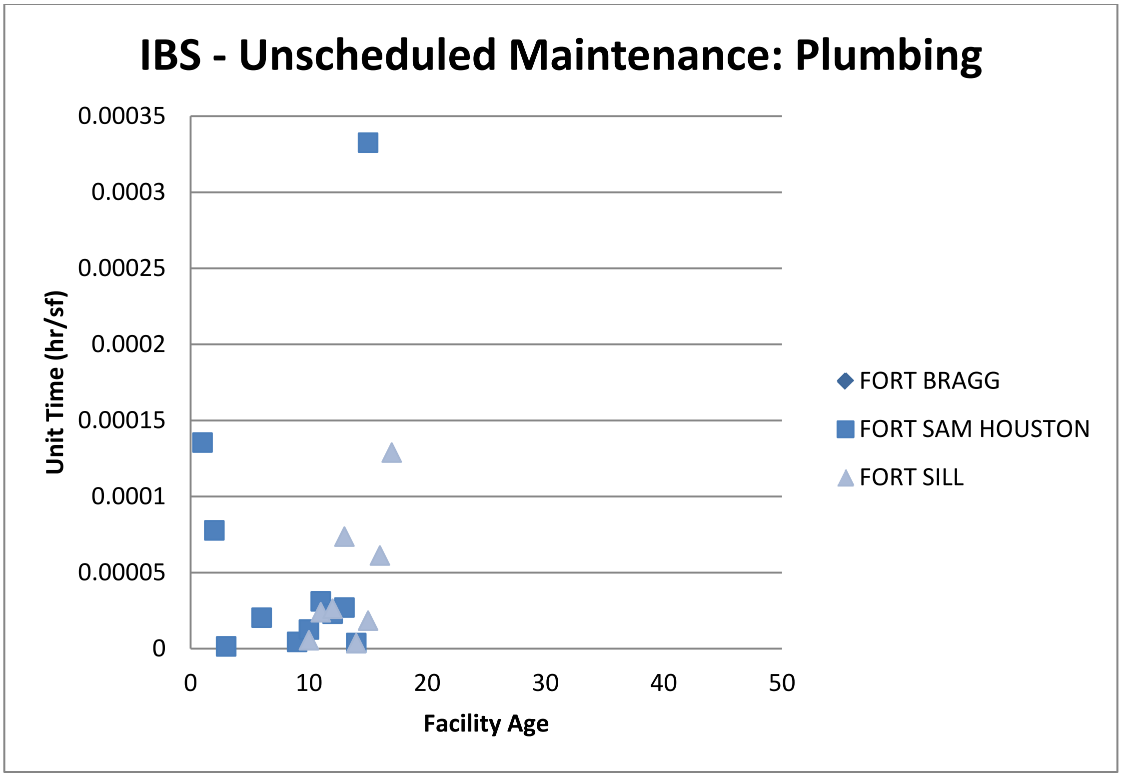

NIBS - Scheduled Maintenance: Interior
0.025
0.02
0.015
0.01
0.005
0
Unit Time (hr/sf)
0
10
20
30
40
50
Facility Age
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT


IBS - Unscheduled Maintenance: HVAC
Unit Time (hr/sf)
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0
0
10
20
30
40
50
Facility Age
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

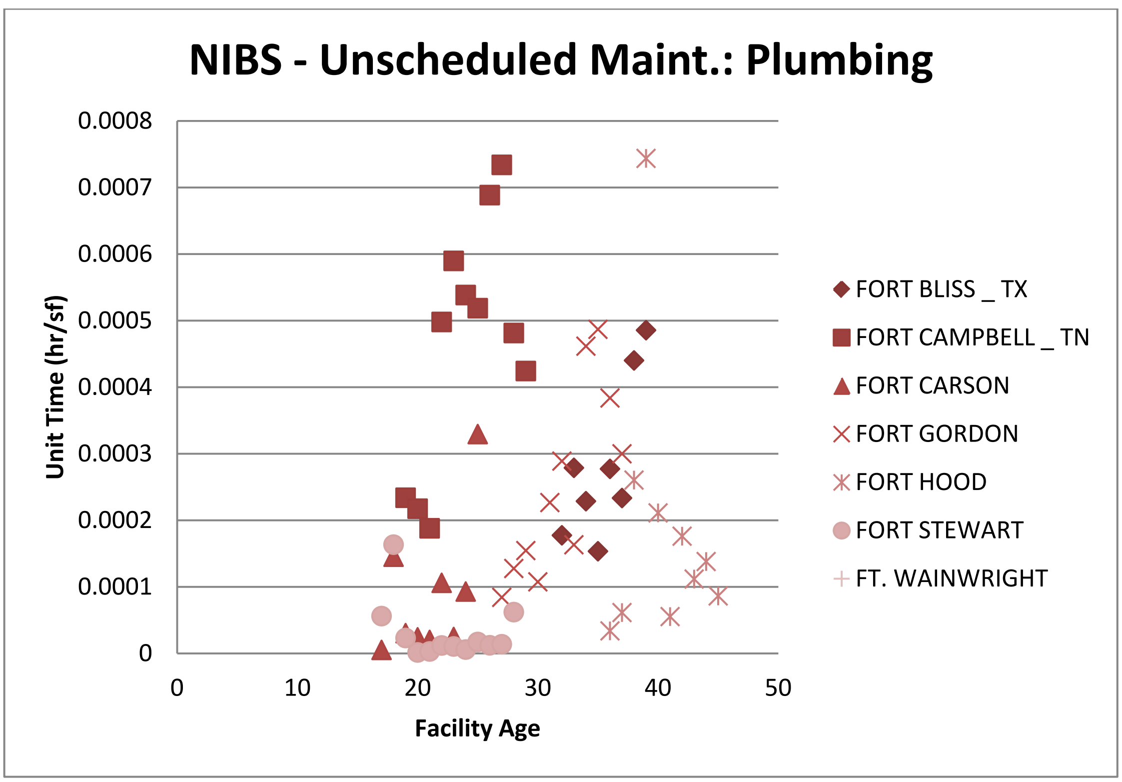

NIBS - Unscheduled Maintenance: HVAC
Unit Time (hr/sf)
0.006
0.005
0.004
0.003
0.002
0.001
0
0
10
20
30
40
50
Facility Age
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT


IBS - Unscheduled Maintenance: Electrical
Unit Time (hr/sf)
0.00025
0.0002
0.00015
0.0001
0.00005
0
0
10
20
30
40
50
Facility Age
FORT BRAGG
FORT SAM HOUSTON
FORT SILL

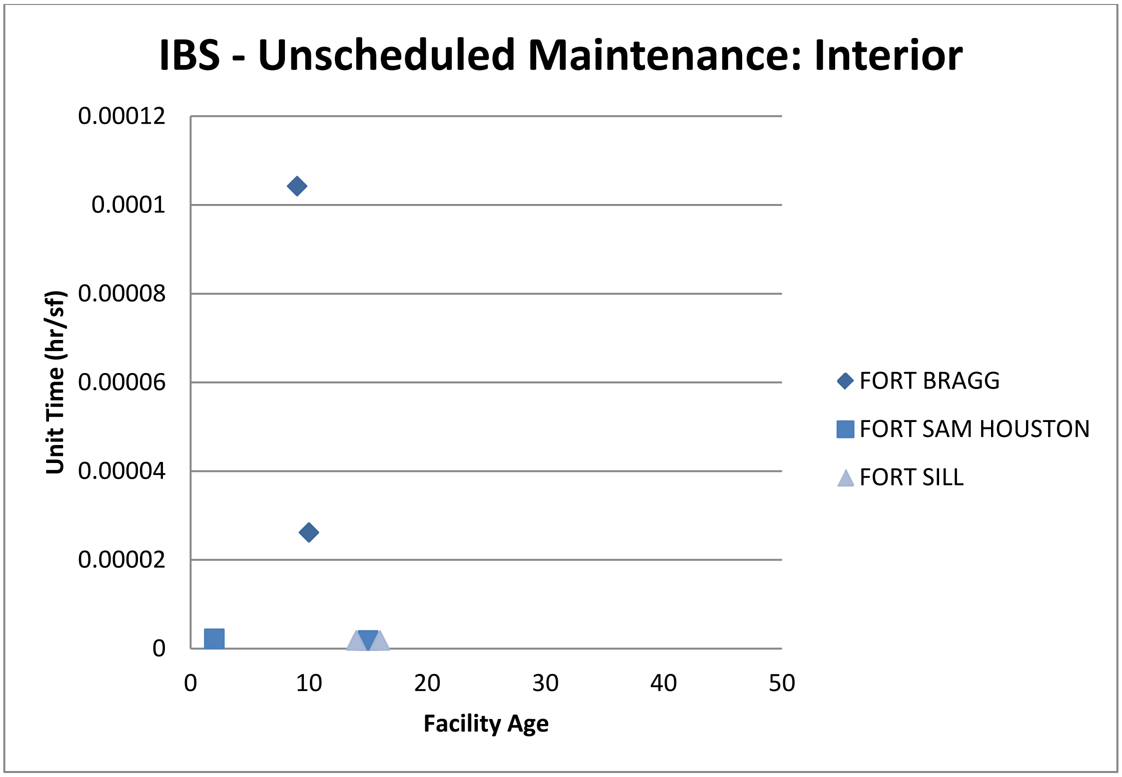

IBS - Unscheduled Maintenance: Electrical
Unit Time (hr/sf)
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
0
10
20
30
40
50
Faiclity Age
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT



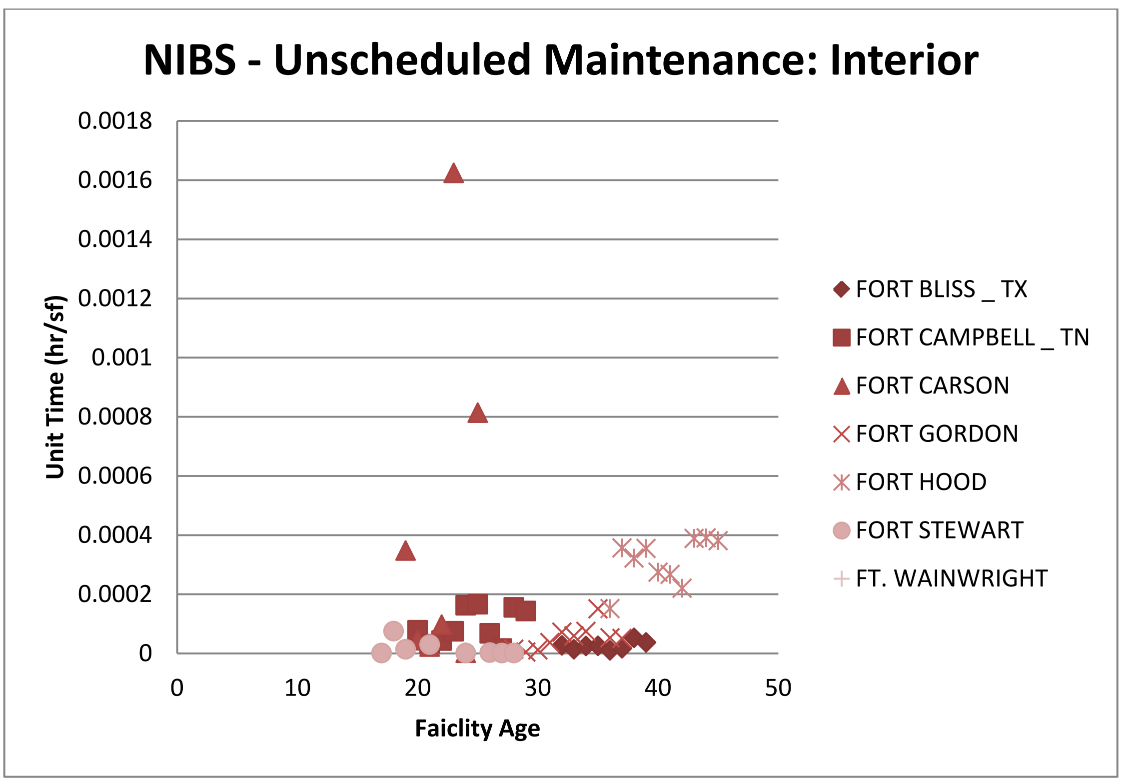
IBS - Unscheduled Maintenance: Plumbing
0.00035
0.0003
0.00025
0.0002
0.00015
0.0001
0.00005
0
0
10
20
30
40
50
Unit Time (hr/sf)
Facility Age
FORT BRAGG
FORT SAM HOUSTON
FORT SILL



NIBS - Unscheduled Maint.: Plumbing
0.0008
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0
0
10
20
30
40
50
Unit Time (hr/sf)
Facility Age
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT



IBS - Unscheduled Maintenance: Interior
0.00012
0.0001
0.00008
0.00006
0.00004
0.00002
0
Unit Time (hr/sf)
0
10
20
30
40
50
Facility Age
FORT BRAGG
FORT SAM HOUSTON
FORT SILL



NIBS - Unscheduled Maintenance: Interior
0.0018
0.0016
0.0014
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
0
Unit Time (hr/sf)
0
10
20
30
40
50
Faiclity Age
FORT BLISS _ TX
FORT CAMPBELL _ TN
FORT CARSON
FORT GORDON
FORT HOOD
FORT STEWART
FT. WAINWRIGHT

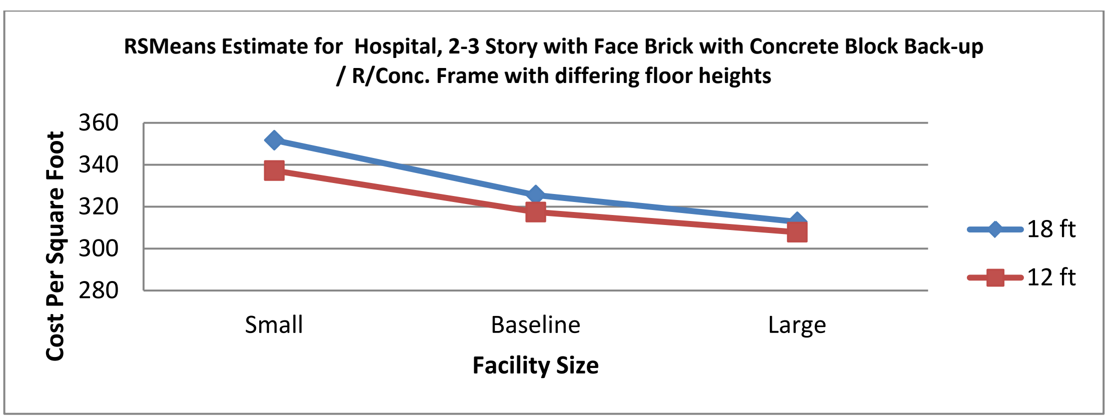
APPENDIX D. CONSTRUCTION COST ESTIMATES

IBS Premium 2-2.5% per resident engineer (Post and Kohn 1995). This range was applied to each of the building systems.

IBS Premium 1.6-4.2% per commercially available cost estimating software (RSMeans 2012). Square foot (sf) ranges included the following: unadjusted baseline was cited at 55,000 sf; minimum range for entry was cited at 21,250 sf; maximum range for entry was cited at 166,750 sf. Minimum story height available for entry was cited at 12 feet. Maximum story height available for entry was cited at 18 feet.

Estimate Name:	Baseline 12 ft	Baseline 18 ft	Small 12 ft	Small 18 ft	Large 12 ft	Large 18 ft
Building Type:	Hospital, 2-3 Story with Face Brick with Concrete Block Back-up / R/Conc. Frame	Hospital, 2-3 Story with Face Brick with Concrete Block Back-up / R/Conc. Frame	Hospital, 2-3 Story with Face Brick with Concrete Block Back-up / R/Conc. Frame	Hospital, 2-3 Story with Face Brick with Concrete Block Back-up / R/Conc. Frame	Hospital, 2-3 Story with Face Brick with Concrete Block Back-up / R/Conc. Frame	Hospital, 2-3 Story with Face Brick with Concrete Block Back-up / R/Conc. Frame
Location:	NATIONAL AVERAGE	NATIONAL AVERAGE	NATIONAL AVERAGE	NATIONAL AVERAGE	NATIONAL AVERAGE	NATIONAL AVERAGE
Story Count:	3	3	3	3	3	3
Story Height (L.F.):	12	18	12	18	12	18
Floor Area (S.F.):	55000	55000	21250	21250	166750	166750
Labor Type:	STD	STD	STD	STD	STD	STD
Basement Included:	No	No	No	No	No	No
Data Release:	Year 2012	Year 2012	Year 2012	Year 2012	Year 2012	Year 2012
Cost Per Square Foot:	$317.44	$325.57	$337.23	$351.72	$307.85	$312.80
Building Cost:	$17,459,000.00	$17,906,500.00	$7,166,000.00	$7,474,000.00	$51,333,500.00	$52,160,000.00

The cost per square foot was plotted for each facility size at 12 foot height and 18 foot height, giving the range of estimated IBS premium percentages.



RS Means Square Foot Costs for 2012 (Section 50 17) list three of the four building systems investigated in this thesis. The median values are as follows:

<u>50 17 00 46 0010 Hospitals</u>

50 17 00 46 2720	Plumbing	$23.50 per sf
50 17 00 46 2770	HVAC	$31 per sf
50 17 00 46	Electrical	$28.50 per sf

Therefore the range of premiums (in $/sf) is as follows:

Premiums	HVAC	Electrical	Plumbing
lowest	0.50	0.46	0.38
medium	0.78	0.71	0.59
highest	1.43	1.31	1.08

APPENDIX E. DECISION TREE ANALYSIS

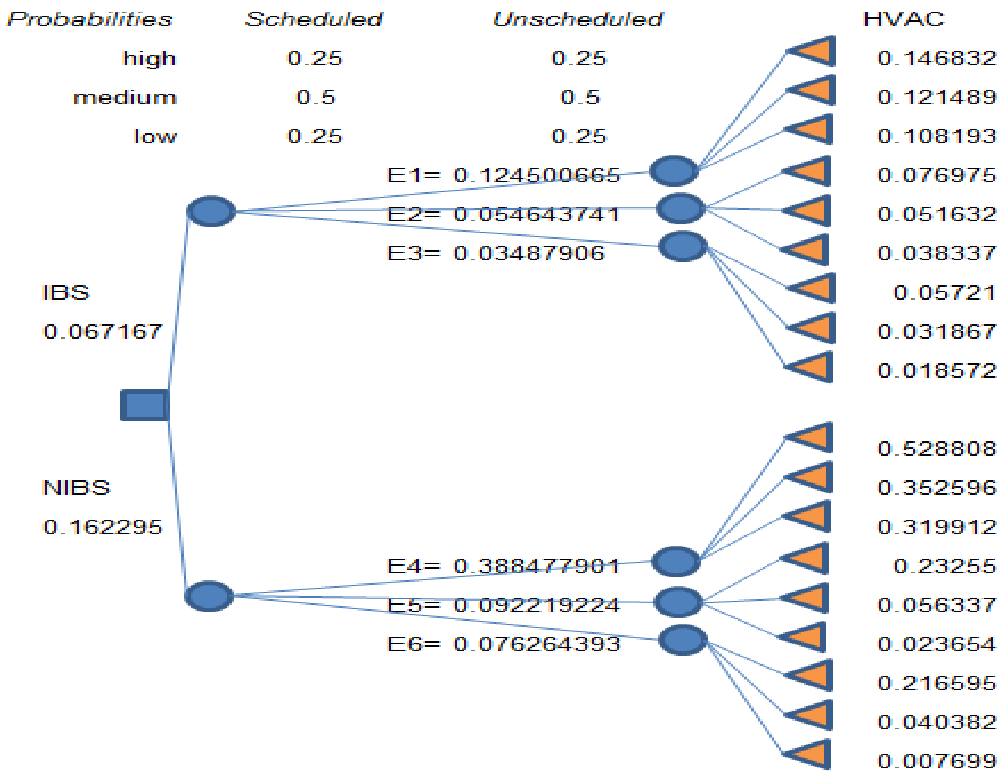
End node (outcome) combinations for scheduled (S) and unscheduled (U) maintenance (adjusted unit costs) were evaluated for each building system.

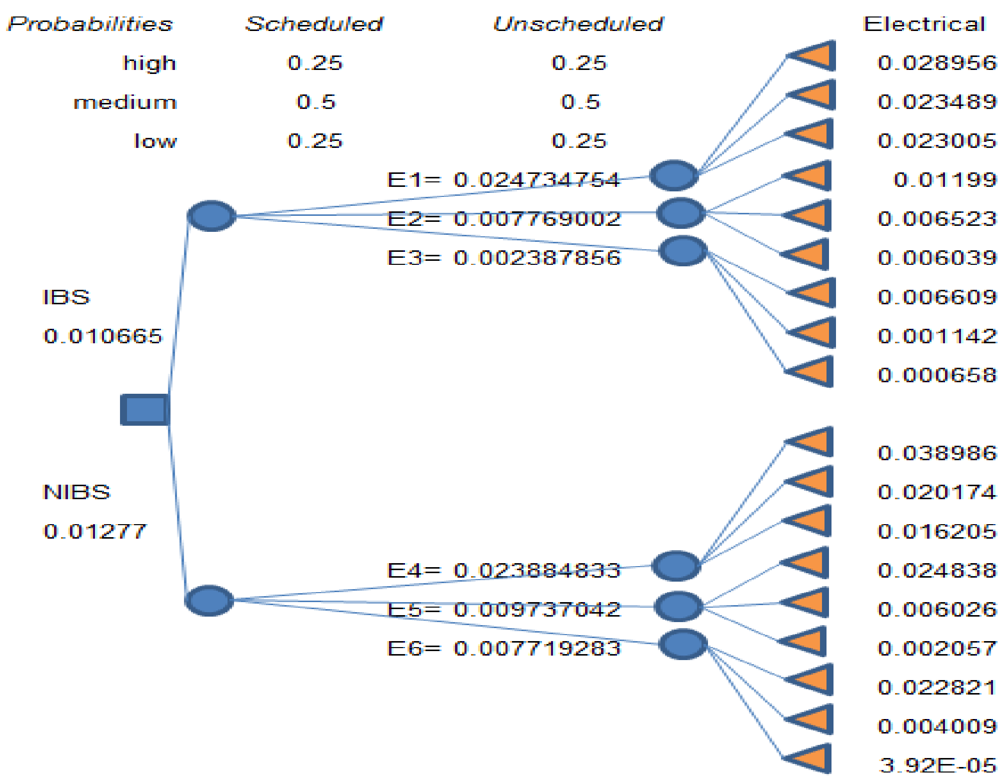
	End Node Combinations	*HVAC*	*Electrical*	*Plumbing*	*Interior*
IBS	high S high U	0.146832	0.028956	0.024659	0.075815
	high S medium U	0.121489	0.023489	0.019757	0.075323
	high S low U	0.108193	0.023005	0.018557	0.075308
	medium S high U	0.076975	0.01199	0.013205	0.016426
	medium S medium U	0.051632	0.006523	0.008304	0.015934
	medium S low U	0.038337	0.006039	0.007104	0.01592
	low S high U	0.05721	0.006609	0.008738	0.001444
	low S medium U	0.031867	0.001142	0.003836	0.000952
	low S low U	0.018572	0.000658	0.002636	0.000937
NIBS	high S high U	0.528808	0.038986	0.046226	0.381925
	high S medium U	0.352596	0.020174	0.024781	0.368597
	high S low U	0.319912	0.016205	0.021314	0.36666
	medium S high U	0.23255	0.024838	0.028027	0.020407
	medium S medium U	0.056337	0.006026	0.006582	0.007078
	medium S low U	0.023654	0.002057	0.003115	0.005141
	low S high U	0.216595	0.022821	0.025152	0.015466
	low S medium U	0.040382	0.004009	0.003707	0.002137
	low S low U	0.007699	3.92E-05	0.00024	0.000201

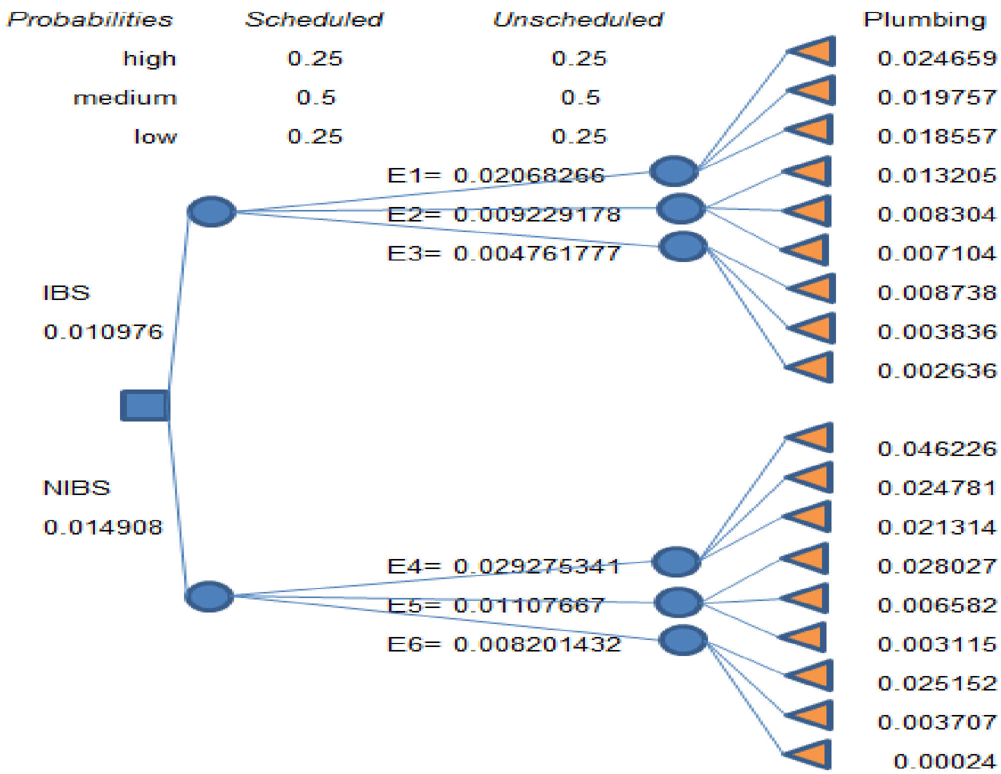
To these end nodes, high=0.25, medium=0.50, and low=0.25 probabilities were applied for scenarios of scheduled and unscheduled maintenance.

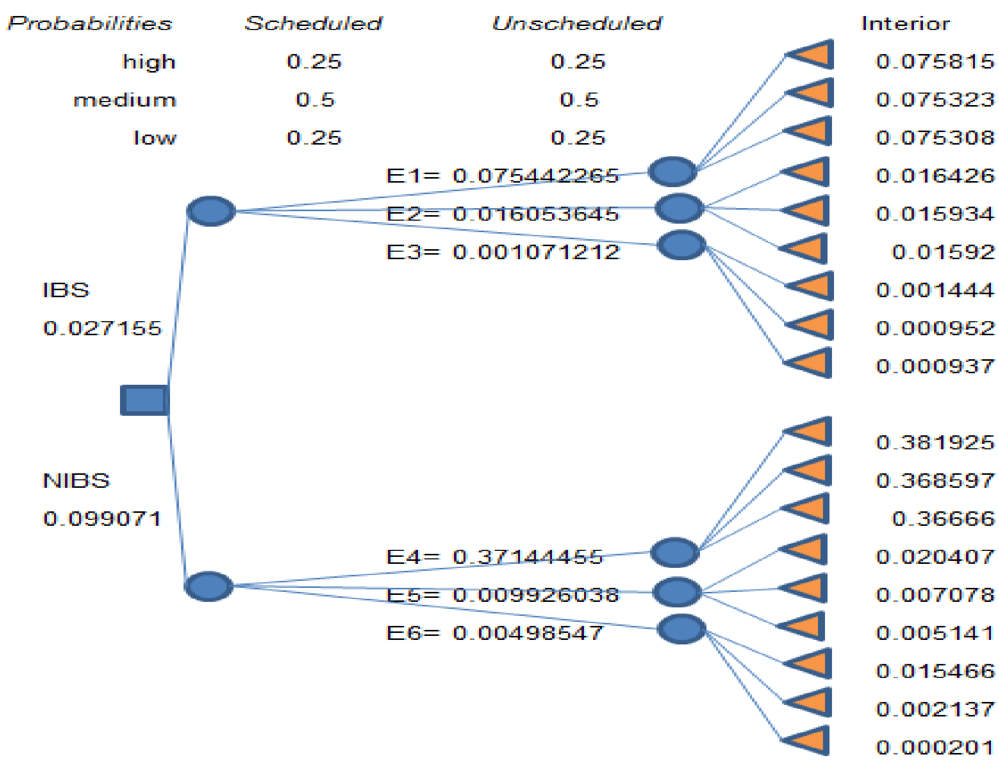
The following charts show the DTA for each building system, with the summary of lifecycle savings ($/sf):

Lifecycle Savings:	HVAC	Electrical	Plumbing	Interior
25 year lifespan	2.38	0.05	0.10	1.80
45 year lifespan	4.28	0.09	0.18	3.24


Probabilities
Scheduled
Unscheduled
HVAC
high
0.25
0.25
medium
0.5
0.5
low
0.25
0.25
E1= 0.124500665
E2= 0.054643741
E3= 0.03487906
IBS
0.067167
NIBS
0.162295
E4= 0.388477901
E5= 0.092219224
E6= 0.076264393
0.146832
0.121489
0.108193
0.076975
0.051632
0.038337
0.05721
0.031867
0.018572
0.528808
0.352596
0.319912
0.23255
0.056337
0.023654
0.216595
0.040382
0.007699


Probabilities
Scheduled
Unscheduled
Electrical
high
0.25
0.25
medium
0.5
0.5
low
0.25
0.25
E1= 0.024734754
E2= 0.007769002
E3= 0.002387856
IBS
0.010665
NIBS
0.01277
E4= 0.023884833
E5= 0.009737042
E6= 0.007719283
0.028956
0.023489
0.023005
0.01199
0.006523
0.006039
0.006609
0.001142
0.000658
0.038986
0.020174
0.016205
0.024838
0.006026
0.002057
0.022821
0.004009
3.92E-05


Probabilities
Scheduled
Unscheduled
Plumbing
high
0.25
0.25
medium
0.5
0.5
low
0.25
0.25
E1= 0.02068266
E2= 0.009229178
E3= 0.004761777
IBS
0.010976
NIBS
0.014908
E4= 0.029275341
E5= 0.01107667
E6= 0.008201432
0.024659
0.019757
0.018557
0.013205
0.008304
0.007104
0.008738
0.003836
0.002636
0.046226
0.024781
0.021314
0.028027
0.006582
0.003115
0.025152
0.003707
0.00024


Probabilities
Scheduled
Unscheduled
Interior
high
0.25
0.25
medium
0.5
0.5
low
0.25
0.25
E1= 0.075442265
E2= 0.016053645
E3= 0.001071212
IBS
0.027155
NIBS
0.099071
E4= 0.37144455
E5= 0.009926038
E6= 0.00498547
0.075815
0.075323
0.075308
0.016426
0.015934
0.01592
0.001444
0.000952
0.000937
0.381925
0.368597
0.36666
0.020407
0.007078
0.005141
0.015466
0.002137
0.000201