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Characterization Patterns of MILCON Project Contract Modifications

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CHARACTERIZING PATTERNS OF MILCON PROJECT CONTRACT MODIFICATIONS

THESIS

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Abstract

Change orders are used by project managers of construction projects to account for unexpected changes in construction projects after the contract has been finalized. This can include everything from weather events to last minute changes requested by the user. This effort analyzed data from the U.S. Air Force Military Construction (MILCON) program to find the major causes of change orders in the hopes that the associated costs may be minimized and that the insight gained may improve project management efforts. The data was analyzed using means comparison testing through the nonparametric Kruskal-Wallis test; the results were then ranked using the Dunn-Bonferroni method.

The results show that pre-construction activities (unforeseen site conditions, unforeseen environmental site conditions, user changes, and design deficiencies) are the most common causes of change orders for MILCON projects, which agrees with other construction research reported in the literature. Although the information contained in the military database was insufficient to determine a conclusive statistical ranking, there is evidence that suggests Air Force Material Command may have higher median change order cost and Air Combat Command has lower median change order costs. When considering the construction agent, the Air Force seems to have higher median change order costs than both the Army Corps of Engineers and the Naval Facilities Command. However, no specific reasons can be attributed to these observations. Furthermore, given the accuracy and completeness of the data, these results remain questionable and require further research to validate.

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Chapter 1. Introduction

Within the strict confines of budget, a diverse and broad cast of conflicting players, and pressures from project requirements, project managers (PMs) must typically exercise all the tools they have to successfully complete a project. The construction contract modification, also referred to as a change order or "mod," is a vital tool used by PMs to address changes in construction projects after a contract has been finalized. In fact, the change order is one of the few tools the PM has to accommodate for unplanned occurrences once the project is under construction. Therefore, having a better understanding of the causes of change that occur during construction may have a significant impact on the PM's ability to manage a project. Consequently, this research effort attempted to identify the major causes contributing to change orders and quantify their effects. The results provide PMs a list of red flags alerting them to potential problems and enable them to develop management strategies to minimize overall costs.

General Background

Simply stated, a change order is a modification of an existing construction contract, which is a binding legal agreement between the contractor and the purchaser that, among other things such as specifying design and materials, details the agreed upon cost and schedule for a project. Any changes to the contract after it has been agreed upon must be negotiated between the contractor and purchaser as a change to the contract using a change order. As broadly defined above, these terms are industry standards and have been defined similarly in many studies (Choy and Sidwall, 1991; Gunhan, Arditi, and Doyle, 2007; Hanna, Russell, and Thomack, 1998).

The negotiation of a change is the change order process and often involves changes in the amount of the total cost of the building. Many change orders are as simple as altering the colors or architectural details. If done early in the project, they usually have no direct impact. However, other change orders have a more direct impact on the project. Events such as major changes to the design, inclement weather, and design errors are all examples of change orders with direct impact. These types of change orders can incur significant additional costs and delays to the original schedule.

Change orders may impact projects indirectly as well. One study found that the average decrease in efficiency of work is 30% while the change work is being performed (Thomas and Napolitan, 1995). In the worst case, excessive amounts of change orders may lead to breach or abandonment of the contract (Richey and Walulik, 2001). Research has also shown that as the amount of change increases on a project, overall productivity decreases; this represents a source of cost escalation and schedule delay (Hanna, Camlic, Peterson, and Nordheim, 2002; Ibbs, 1997; Leonard, 1987; Vandenberg, 1996).

While change orders may bring increased cost, schedule delay, and indirect costs through lost productivity, they are considered inevitable (Cox, 1997). In fact, change orders give the PM a vehicle by which to maintain project momentum (Ehrenreich-

Hansen, 1994). "It is a common perception that change orders are undesirable and that their number should be as close to zero as possible. Actually, [change orders] are a very necessary and useful tool in quality and risk management of projects" (Ehrenreich-Hansen, 1994). Industry has recognized that management of change orders is clearly a crucial element of any project. Project managers must be able to effectively deal with change and manage their impact (Cox, 1997). The focus of this research, understanding the potential causes and impact of change orders, provides critical insight regarding effective management strategies.

Specific Background

The United States (U.S.) Air Force executes a very large construction program each year. In 2006, the Air Force Military Construction (MILCON) budget was $1.28 billion (Dodge, 2006). Of that amount, $64 million (approximately 5%) was set aside as contingency funding for change orders on MILCON projects (AFCEE, 2000). As previously asserted, change orders are inevitable and the Air Force has recognized this by establishing these contingency funds. Furthermore, Air Force PM guidance lists change orders as a vehicle by which a PM can accommodate for discrepancies in the plans and specifications, changes requested by owners/users who have altered the project goal in some way, or simply things that could not be foreseen (AFCEE, 2000).

However, research has shown that funding change orders at the current 5% level is likely to be inadequate (Cook, 2006). This indicates that budget controls may not be addressing spending in a manner consistent with current practice. For instance, Cook

(2006) found that the $64 million set aside as contingency funding only covered about half the predicted change order costs. Therefore, it is critical that change order (i.e., contingency) budgets are effectively managed. Knowing the most common causes of change orders gives a PM the ability to scrutinize a project prior to contract award, thereby helping him or her avoid pitfalls that may have plagued past projects. Presently, however, the PM has no source for this information.

When a user, key player, or contractor submits a request for a change order, the PM is typically the first person to review that request. Although many change order requests must be forwarded to and approved by other key players, the PM may be able to give unofficial approval or disapproval. In other words, PMs control change orders by acting as the first filter and at times the decision maker when a change arises. However, there is very little official guidance provided to Air Force PMs (Arin, 1989). Compounding the problem, external elements like available funding often take precedence over other factors (Arin, 1989; AFCEE, 2000). Therefore, any information that helps a PM control costs will result in a more successful project. An understanding of the common causes and impacts of change orders is essential so the PM can make wise decisions as he or she approaches a project. Additionally, this understanding will give the PM the ability to convey the consequences of the change to decision makers and other key players.

Problem Statement

Given that change order budgets are potentially under-funded, it is imperative that existing funds are managed in the most efficient manner possible. Presently, information regarding change order causes and impact across the Air Force does not appear to exist. This is reinforced in the Air Force Project Manager's Guide, which states, "It takes experience and a *gut feel* to be a good project manager" (AFCEE, 2000). Therefore, change order causal and impact information in a digestible format would serve as an inexpensive and valuable means by which PMs could build on the past experience of the Air Force. Increasing PM experience would aid in maximizing the efficiency with which contingency budgets are spent.

Research Questions

This research contributes to the body of knowledge required to answer the overarching question, "What can be done to maximize the value of MILCON project funding?" Specifically, this effort answers the question, "What are the causes of change orders within the Air Force MILCON program?" Additionally, this research ranks causes of change orders by their magnitude of impact. Finally, the question, "What does the Air Force presently do to capture and preserve experience gained through executing change orders in the past?" is also answered.

Methodology

This research effort collected archived data by gathering project information from MILCON program managers and querying an existing Air Force database containing information on MILCON projects. Program managers were asked for electronic copies of contractual documents for projects completed from the year 2002 through 2006. The Air Force database containing MILCON information was queried for completed project information from the years 2000 through 2004. Using a small sample of the collected project data and information gathered during the literature review (Chapter 2), a list of potential change order causes was developed. The project data gathered from the program managers and the database was then categorized by potential change order causal factor. The results were analyzed using the nonparametric Kruskal-Wallis test and those results were ranked using the Dunn-Bonferroni method. The results drawn from those tests are presented in Chapter 4 and final conclusions are presented in Chapter 5.

Assumptions and Limitations

Because the requested data was recorded during project execution by PMs and contracting officers, it was assumed to be recorded correctly. Therefore, no effort was made to verify the accuracy of the data. It was also assumed that the data consisted of projects that were independent of one another and that change orders on one project did not affect change orders on another project. It was also assumed that the submitted projects were representative of the Air Force MILCON program as a whole because of the broad variety of projects executed in a large number of different locations.

The primary limitations of this research effort were the quantity and quality of submitted data. Additionally, there was an inherent reliance upon data that was not standardized. Because there is not a list of standard change order causes that Air Force PMs are required to use, assigning a change order causal factor required a subjective grading. This grading process introduces the possibility for personal bias; however, a protocol was established early in the effort to minimize any effect of bias. This is discussed in detail in Chapter 3.

Overview of Remaining Chapters

The remaining chapters of this thesis present the literature review and results of this research effort. Chapter 2 presents the current status of research regarding change orders in the construction industry. It covers the industry as a whole and narrows to the government sector. Chapter 3 presents the methodology used to complete this research, highlighting the gathering of data, the protocol used to prevent bias, and the statistical tools used to evaluate the data. Finally, Chapter 4 provides the results and Chapter 5 summarizes the effort with a conclusion and recommendations.

Chapter 2. Literature Review

This chapter reviews the state of existing research completed on change orders as they relate to the present research effort. The chapter begins with a short background section that introduces the concept of what constitutes change and a change order. This is followed by a review of research investigating the potential impacts of change on a project. The chapter then covers existing studies germane to the present effort, beginning with the construction industry as a whole and narrowing to work specific to the Department of Defense (DoD). Finally, the reviewed literature is synthesized into a presentation of common causal factors of change orders, closing with a brief discussion of key causal factors identified in this review.

Background

It is recognized universally throughout the construction industry that projects will experience some degree of change. This is evidenced by the inclusion of contract provisions providing for change, called change clauses, in most construction contracts (Richey and Walulik, 2001; FAR, 2005; Cox, 1997). Understanding what constitutes change during a construction contract is necessary prior to being able to study the causes of change and hence change orders.

Types of Change – Legal Definitions

Litigation and contract law have defined several different types of change that may occur between the parties of a construction contract. There are generally three types of change that may occur: formal changes, constructive changes, and cardinal changes (Cox, 1997). Formal changes, also called change orders, are those in which the contractor is given documentation from the other party (often called the owner) directing some change to the original contract documents (Cox, 1997). It is this type of change that is the subject of the current research. Constructive changes are changes to the work that the contractor must make as the result of an action by the owner. Examples of this are errors in the contract documents provided to the contractor at the beginning of the project or changes to the work directed by the owner outside the formal processes provided for within the original contract (Cox, 1997). Constructive changes can and often do become formal change orders. Finally, a cardinal change is a change in the scope of the agreed upon work of the project (Cox, 1997). This type of change is akin to contracting for an apple and then directing the contractor to provide an orange. A cardinal change may consist of one change or the cumulative effect of numerous changes and is typically determined by the courts. If a cardinal change has occurred, costs are awarded or assessed to each party by the legal system (Cox, 1997; Richey and Walulik, 2001).

What is a Change Order? – Working Definition

While the legal system has clearly defined what a change order is, the term is rather generic within the construction industry. The R.S. Means Construction Dictionary

(2003) defines a change order as simply a modification to the original contract documents (plans, specifications etc.) formally given to the contractor in writing. Researchers have referred to a number of textbooks, educational materials, or government regulations, and arrived at similar definitions (Chan and Yeong, 1995; Günhan et al., 2007). Others have noted that change orders are not always formal documents and include formal and constructive changes (e.g., Hanna et al., 1998). Choy and Sidewell (1991) avoid the term altogether and refer to the general term, contract variations, in their effort to document the causes of change orders. The regulations governing acquisition within the federal government define a change order as, "a written order, signed by the contracting officer, directing the contractor to make a change that the changes clause authorizes the contracting officer to order without the contractor's consent" (FAR, 2005).

The definition provided by the Federal Acquisition Regulations (FAR) encompasses the critical elements of the definition of a formal change generally used by industry as described by Choy and Sidwell (1991); Chan and Yeong (1995); Cox (1997); Hanna et al. (1998); Richey and Walulik (2001); and Günhan, Arditi, and Doyle (2007). The current research effort utilizes the FAR definition since data was collected from a federal source. It is through this lens that the works presented here have been evaluated. Chow and Sidwell's (1991) definition of variation infers that the causes of change orders cannot be separated from the causes of the impacts of change orders. Experience supports this, particularly in federal construction. The impacts of change orders discussed here typically include lost productivity on the jobsite, cost overruns, and delay. On federal projects, each of those things must be accounted for through the use of a change order (FAR, 2005). The causes of both change orders and the impacts of change orders, for the purposes of this study, are thus directly comparable.

Impacts of Change Orders

The study of change orders is valuable because it gives project managers and other practitioners in the field tools through which they might avoid some of the negative impacts associated with change orders. Change orders can range from having no impact on a project to causing the complete abandonment of a project (Richey and Walulik, 2001). While the degree of impact caused by change orders can vary, past research has demonstrated that the greater number of change orders a project experiences, the greater likelihood the project will be impacted in some manner by change, typically cost growth or schedule delay (Gunduz and Hanna, 2005; Hanna et al., 2002; Hanna, Russell, Nordheim, and Bruggink 1999a; Hanna, Russell, and Vandenberg, 1999b; Vandenberg, 1996). Since the literature primarily addresses risk of impact in terms of lost productivity and cost overruns, limiting the amount of change orders also limits the amount of risk on a project. The discussion below presents the potential impact of change orders in those terms.

Productivity

Leonard (1987) studies the measure of percent change orders (the percentage of labor hours spent on change work vs. the labor hours spent on original contract work) compared to percent loss of productivity (percent unproductive labor hours vs. labor hours spent on original contract work). His results show “a significant direct correlation between percentage loss of productivity and percentage change orders" (Leonard, 1987:2). On a project with a 25% change order rate, electrical/mechanical work experienced a 20% loss of productivity and civil/architectural work experienced a 17% loss; if the CO rate increased to 50%, respective work types experienced a 31% and 23% loss of productivity (Leonard, 1987).

Research by Thomas and Napolitan (1995) supported Leonard's (1987) results. They compared the labor hours required to accomplish a specific task during both a normal schedule and change work to calculate productivity rates, which were then used to calculate performance ratios during normal work and change work. These ratios were divided by one another to calculate efficiency. Statistical regression was used to test significant contributing factors affecting performance ratios for correlation; an analysis of variance test was then completed on each factor to show the efficiency impact of each factor. Thomas and Napolitan (1995) concluded that during change work, projects suffer an average 30% loss of efficiency and the timing of the change (that later in the project the greater impact) plays a crucial role in affecting efficiency.

Ibbs (1997) expanded upon Thomas and Napolitan's work using a different approach. Where Thomas and Napolitan (1995) analyzed several crews over two and a half years, Ibbs (1997) surveyed a large number of organizations within the industry utilizing a standardized questionnaire that he developed with the Construction Industry Institute. He assessed change orders vs. productivity during the design and construction phases and found that as change increases on a project, productivity declines. During the design phase, Ibbs (1997) found that for every 10% increase in change, productivity decreased by 2.48%; for every 10% increase in change during construction, there was a corresponding 3.44% decrease in productivity. These results show that change has more impact when it occurs during the construction phase of the project (Ibbs, 1997). This supports Thomas and Napolitan's (1995) finding that change had greater impact the later it occurred in a project.

At the same time Ibbs (1997) was completing his study, Vandenberg (1996) was completing his thesis on the impacts of change orders on the efficiency of construction labor working on mechanical systems. Vandenberg's thesis later served as the foundation for his collaboration with Hanna and Russell (1999b). In their work, Hanna et al. (1999b) utilized the total number of direct labor hours minus the original estimate plus the change order estimate divided by the total number of direct labor hours. The published results from their work represent further confirmation of the previous researchers' results. Hanna et al. (1999b) confirmed not only that projects with a higher percentage of change are more likely to be impacted by change, but also that projects impacted by change are less efficient. They additionally confirmed the findings that change during the latter part of a project has greater impact (Hanna et al., 1999b).

Hanna et al. (1999a) published an additional study investigating the impact of change orders on the efficiency of electrical work. Using the same method of measuring efficiency used by Hanna et al. (1999b), Hanna et al. (1999a) found that as change work increases, so does the likelihood of decreases in efficiency. Additionally, Hanna et al. (1999a) further confirmed the works of previous researchers that the later a change occurs, the greater its impact will likely be. One notable difference, however, was that they were able to find statistical evidence that showed the amount of project manager experience correlated with the ability to mitigate the impacts of change work (Hanna et al., 1999a). Earlier efforts had been unable to statistically support this (Hanna et al., 1999b; Vandenberg, 1996).

In terms of loss of productivity, research has shown that change causes productivity losses. Research also indicates that the timing of change is important and that change later in projects is associated with greater losses of efficiency. Interestingly, research has not shown any improvement in terms of being able to accommodate change and maintain efficiency during a project.

Cost Overruns

Many studies have directly or indirectly addressed the impact of change orders in terms of cost overruns, also termed cost growth and cost escalation. As can be seen in the "causes of change orders" section of this chapter, change order causes are often identified and characterized by cost overrun information. This is particularly true on federal projects because changes in cost must be accounted for through the use of a change order (FAR, 2005). The studies reviewed below offer evidence which demonstrates the impact of cost overruns on projects.

Jahren and Ashe (1990) introduced the term "change order overrun rate" to the cost overrun vocabulary, thereby recognizing the inextricable link between cost and change. Analyzing Naval Facilities Command (NAVFAC) data from 1,576 projects using nonparametric testing, Jahren and Ashe (1990) investigated potential predictors of cost overrun and found that large projects are more likely to experience cost overrun rates of 1% to 11% as opposed to smaller ones. Additionally, they observed that projects with initial award amounts less than the government estimate had a higher risk of cost overrun. Although the sample size was relatively large, the data did not meet the assumptions required for typical statistical measures and nonparametric assessments had to be utilized, thus limiting the overall fidelity of potential results (Jahren and Ashe, 1990).

Burati, Farrington, and Ledbetter (1992) subsequently published a study on quality deviations in design and construction. They surveyed members of the Construction Industry Institute (CII) and completed a detailed study of nine projects. While the goal was to demonstrate the causes of deviations or project change, they found an average 12.4% cost overrun (Burati et al., 1992). This coincides with the higher end of the range presented by Jahren and Ashe (1990).

Another study addressing cost growth on military projects was completed by Barrientez (1995). Similar to Jahren and Ashe (1990), he studied NAVFAC projects with the goal of identifying causes of change orders. Using a combination of descriptive statistics and sensitivity analysis performed on 157 change orders over 58 separate contracts, Barrientez (1995) determined an 8.3% cost escalation as the result of change orders executed post award. These results support the findings of Jahren and Ashe (1990) and are within the range determined by Burati et al. (1992).

Cox, Morris, Rogerson, and Jared (1999) approached change orders using the case study technique. This effort studied two construction projects in the United Kingdom in detail from contract award to completion, tracking each change. They found a 5-8% cost overrun as a result of change orders (Cox et al., 1999).

An oft-cited study of cost overruns in infrastructure projects is Flyvbjerg, Holm, and Buhl (2004). Their study spanned 258 transport infrastructure projects in 20 different nations and was the first and largest of its kind when published (Flyvbjerg et al., 2004). Using regression and analysis of variance to determine the causes of cost overrun, Flyvbjerg et al. (2004) found that costs typically increase an average 4.64% per year on large transportation infrastructure projects as a result of change orders. On the famous "Chunnel" project, this amounted to $1Millon/day (Flyvbjerg et al., 2004).

Hsieh, Lu, and Wu (2004) studied 90 public works projects in Taiwan. They found that most change orders resulted from problems in planning and design and contributed between 10-17% to project cost; they also presented a well-founded argument to incorporate change management into the overall project management plan (Hsieh et al., 2004). Their results are in concert with the findings of Jahren and Ashe (1990), Burati et al. (1992), and within the range reported by Barrientez (1995).

Odeck (2004) used regression analysis of data from the Norwegian Public Roads Administration to build and test a model that will predict cost overruns based on a variety of factors he found to be significant contributors. He found a mean cost overrun of 7.9% and that cost overruns were more likely to occur in smaller projects as opposed to larger ones (Odeck, 2004). This is a departure from Flyvbjerg et al. (2004) which found the likelihood of cost escalation to be high for all sizes of transportation projects. Odeck's results support the finding of the previous researchers.

Nassar, Nassar, and Hegab (2005) focused on paving projects completed by the Illinois Department of Transportation (IDOT). Working in a vein similar to Odeck

(2004), they utilized data from 219 IDOT projects to develop a frequency distribution of the causes and effects of cost overrun. This effort reported an overall average cost overrun of 4%. While this value is low, it is within the range found by Jahren and Ashe (1990). It should be noted though that Nassar et al. (2005) focused solely on asphalt paving projects as opposed to other efforts which included multiple types of construction.

Dantata, Touran, and Schneck (2006) completed an interesting study in cost overrun comparison. They compared the cost overruns on light rail projects from 1994 to 2004 with those of an earlier study that investigated projects from 1984 to 1990. Dantata et al. (2006) tested the means of the year groups using a *t*-test to determine if there were any differences. While the results were not conclusive, they did indicate that cost overruns in light rail construction did seem to be decreasing (Dantata et al., 2006). Their research is unique because it is the only effort that seems to suggest a gradual decreasing trend in cost overruns.

Cook's work (2006) was the most recent study to address cost escalation within the DoD, and specifically the Air Force. Cook analyzed a large database of Military Construction (MILCON) projects to develop and test a predictive model of cost overruns. The study found that the typical project experienced a cost overrun of 11.6% (Cook, 2006), which is in concert with the results of previous researchers cited in this section.

The Government Accounting Office (GAO) recently completed studies on both courthouse construction and major construction within the Department of Energy (DOE). Cost growth in these programs was observed to be 5% and 50%, respectively (GAO, 2005; GAO, 2007). Another study completed by the GAO on the Federal Highway

Administration in 1997 reported that 23 of 30 projects reviewed had experienced cost growth and that half of those had growth greater than 25% (GAO, 1997).

Günhan et al. (2007) work on public school construction is another source of data regarding the impact of change orders in terms of cost overrun. They tracked the annual cost overrun of a school district as the ratio of change order value to contract value. Günhan et al. (2007) cite overruns ranging from as high as 12% to as low as 2.5%, with an average of roughly 5%. Again, these results coincide with those already presented.

Summation

With reported cost overrun results ranging from 1% to 25%, a cost overrun of 10% to 15% in not unrealistic. Coupling these results with the consideration of the established losses of productivity that also occur due to change work, it seems as though addressing the causes of change orders can potentially provide valuable project savings. These savings can be realized both in terms of actual project cost and intangible costs associated with improved productivity.

The Causes of Change Orders

A number of studies investigating the causes of change orders have been completed in recent years. These studies cover everything from large infrastructure projects in metropolitan locations to small irrigation projects in less developed countries. They take varied approaches. Some are completed via survey of industry professionals, others using public data, still others are case studies of specific types of projects such as public school construction. Presented first are general industry studies followed by studies completed on behalf of or completed using data provided by the DoD. The culmination of these efforts provides common sources of cost overruns and avenues of potential investigation. This section concludes with a summation of change order causes as documented by industry research.

Industry Studies

Among published works in North America, Diekmann and Nelson (1984) stands out. Frequently cited both domestically and abroad, this effort represented a shift in industry focus on change order causes by using descriptive statistics to show a new direction in research was needed; much of the literature until that time focused on other causes of change such as differing site conditions, mismanagement, and delay. Diekmann and Nelson (1984) analyzed 22 federally administered projects and found that 72% of change order causes originated from design error and user changes. Differing site conditions accounted for 15% of claims while weather, labor strikes, and other causes accounted for the remainder (Diekmann and Nelson, 1984). Although the results were purely descriptive and did not include any statistical analysis, the research changed the focus of study within the industry.

Arditi, Akan, and Gurdamar (1985) blazed an early path in studying the causes of change orders with their benchmark effort studying public sector projects in Turkey. Alarmed by an average 30% cost increase on school and hospital construction, they surveyed contractors and public servants to collect data on 384 different projects completed from 1970 to 1980. The research effort was challenged by high inflation during the study period and the researchers suspected that data reported on the public projects were possibly handpicked to represent the best cases. Arditi et al. (1985) found four primary reasons for cost overruns. Presented in order of importance by relative weight, the reasons for cost overruns in Turkey from 1970 to 1980 were: inflation and economic circumstances of the nation, government policy, resource shortages, and inaccurate estimates of project cost due to incomplete plans and specifications at critical moments during project timelines. Juxtaposed against Diekmann and Nelson (1984), it is clear that economic and societal conditions external to projects make it difficult to compare the efforts to one another. It is that much more noteworthy that both efforts cite design issues as a contributing factor.

Foundational efforts regarding changes orders and construction productivity include many of the researchers cited earlier in this chapter. Leonard's (1987, 1988) work represented a great stride forward as he was among the first to use field investigation as opposed to survey work. Partnering with a professional construction management firm, he investigated 57 different projects that had high levels of change to examine the causes of change orders and how change orders contributed to productivity loss (Leonard, 1988). Using descriptive statistics, Leonard (1987) found that 65% of change orders were caused by design errors and omissions and 35% were caused by design changes (requested by either the user or the A/E). Leonard (1987) further developed standard productivity curves to estimate loss for specific types of work, estimating productivity losses as high as 50% in some cases. The principal finding of his work is that the majority of changes orders are caused by either design errors and omissions or owner and A/E changes (Leonard, 1988).

Dlakwa and Culpin (1990) followed the methodology used by Arditi et al. (1985) to investigate work in Nigeria by surveying industry professionals. Where Arditi et al. (1985) included only public agencies and contractors, Dlakwa and Culpin (1990) cast a broader net to include other professionals such as architects, engineers, and consultants. Similar to Arditi et al. (1985), Dlakwa and Culpin (1990) found that economic and political circumstances were the primary factor in cost overruns, followed by construction delays (caused by resource shortages), inadequate planning, and deficiencies in initial estimates. Both studies seem to indicate that in less developed countries geo-economics may play a larger role in cost overruns than local factors.

Choy and Sidwell (1991) published an oft-quoted work on variation in Australian construction contracts. A number of studies cite their definition of variation, including the works of both Alwi (2003) and Chan and Yeong (1995). Choy and Sidwell (1991) used a survey and descriptive analysis of 32 case studies collected from industry to find that two major sources (design document deficiencies and user requested changes) accounted for 76% of change on the subject projects.

Burati et al. (1992) subsequently published his study on quality deviations in design and construction and not only confirmed Leonard's (1987, 1988) findings but expanded upon them. Burati et al. (1992) also reported that design errors and omissions constituted 78% of total deviations and 79% of total overrun cost. Construction changes and errors comprised another 16% of total deviations and the remaining 6% was distributed among other factors.

Assaf, Al-Khalil, and Al-Hazmi (1995) expanded survey techniques for changes and performed an analysis of schedule delay. They focused on contractors, owners, and A/E firms as opposed to Choy and Sidwell's (1991) focus on contractors. Assaf et al. (1995) surveyed 48 construction professionals in Saudi Arabia and assessed their opinions for cause of delay using a standardized questionnaire. Using inferential statistics to perform an analysis of weighted rankings, they found that contractors, owners, and A/Es generally agree on the causes of change orders. However, when measured specifically, A/Es and contractors tend to agree with each other and owners tend to agree with neither party (Assaf et al., 1995). The analysis also showed that the leading causes of change were financing, requests by owners for special materials, lack of manpower (resources), owner changes, design errors, and the relationships between the parties as the top causes of delay (Assaf et al., 1995). As Dlakwa and Culpin (1990) found, the general economic and political circumstances of a location play an important role in project cost. The findings of Assaf et al. (1995) are interesting because they represent the inklings of a bridge between studies completed in less developed countries and the modern world, specifically Arditi et al. (1985) and Dlakwa and Culpin (1990). Assaf et al. (1995) focused on the same change causes that researchers in North America and Europe focused on prior to Diekmann and Nelson's (1984) effort.

Previously cited in the cost overrun section of this chapter, Cox et al. (1999) used the case study technique to examine projects from start to completion. They found the most common reasons for change orders were errors and omissions in the design documents, user changes, and unforeseen site conditions (Cox, et al., 1999). This is consistent with the work of previously cited researchers.

Love and Li (2000) approached the causes and costs of rework in much the same manner as Cox et al. (1999) approached change orders. They used the case study technique to address rework as a measure of quality on Australian projects and found that the major causes of rework in both subject projects were errors and omissions in design documents and user changes (Love and Li, 2000). While change orders and rework are not always directly comparable, the two major causes of rework (design errors and omissions and user changers) identified by Love and Li (2000) parallel similar causes of change orders identified by other studies (e.g., Diekmann and Nelson, 1984; Leonard, 1987, 1988; Choy and Sidwell, 1991; Burati et al., 1992; Cox et al., 1999).

Al-Momani (2000) expanded the work of Assaf et al. (1995) regarding the causes of schedule delay. He surveyed 130 projects in Jordan considered to have unsatisfactory performance and found the two most significant causes of delay to be poor design and change orders; these were followed by weather, unforeseen site conditions, resource shortages (late delivery), and economic conditions (Al-Momani, 2000). He confirmed the validity of his results with regression models accounting for approximately two-thirds of total variation.

Hanna et al. (2002) authored a study using the same measure of efficiency used by previous efforts to develop a predictive model of change order impact to a project (Hanna et al., 1999a,b; Vandenberg, 1996). Their research effort yielded several factors that serve as predictors of potential impact to projects by affecting productivity (Hanna et al., 2002). Of significance, they found that projects not impacted by change orders had a lower percentage of change orders due to design errors and omissions. Additional factors that could potentially impact productivity were schedule compression (through the use of overtime and over manning), the amount of change, absenteeism and turnover, manpower increase over planned levels, and the processing time from the initiation to approval of a change order (Hanna et al., 2002).

Alwi (2003) measured productivity by surveying Indonesian contractors and analyzed their results with respect to 53 different variables derived from a literature review. These variables were classified as waste categories or waste causes and a survey was developed to test these variables. The results were analyzed using a weighted score model and key variables were identified and then ranked using statistical testing. Alwi (2003) described the causes of productivity loss in order of significance as: design changes, labor issues, and poor management.

A more recent effort to document delay and cost overruns in less developed regions of the world was completed by Frimprong and Oluwoye (2003). The study focused on water projects in Ghana and was based in large part on the works of Arditi et al. (1985), Dlakwa and Culpin (1990), Assaf et al. (1995), and Al-Momani (2000). Utilizing a methodology similar to Assaf et al. (1995), they surveyed contractors, owners, and consultants and used a similar statistical method to analyze the data. Similar to Assaf et al. (1995), Frimprong and Oluwoye (2003) found financing, economic conditions, natural conditions, and materials (resources) to be the top four causes.

In addition to the cost overrun findings previously cited in this chapter, Hsieh et al. (2004) developed a list of change order causes based on a literature review and investigated 90 public works projects in Taiwan. They first classified change orders into categories and then analyzed projects by cost variance, schedule variance, frequency of change orders, the total addition and subtraction due to change on a project, the proportion of change on a project, and the contribution of change to a project. Using analysis of variance to test the proportion and degree of change of each change category, they found that most change orders arose from problems in planning and design (Hsieh et al., 2004).

A pair of studies completed by Wu, Hsieh, and Cheng (2004) and Wu, Hsieh, Cheng, and Lu (2005) was based on a case study analysis of over 1,000 change orders on the Second National Highway project in Taiwan. Both studies cited a combination of geological conditions and thoroughness of geologic survey during design as a primary cause for most change orders (Wu et al., 2004, 2005). Wu et al. (2005) concluded, "In the life cycle of construction engineering, the ratio on [*sic*] the cost of planning and design is low, but its influence to the entire engineering is the largest of all." These results support the general theme of the previously cited research that design errors and omissions are a leading cause of change orders and project change.

Georgy, Chang, and Zhang (2005) conducted research on the narrow sector of industrial construction performance. They developed a questionnaire to measure engineering performance in the industrial construction sector and surveyed 22 contractors (Georgy et al., 2005). The data was analyzed using a variety of descriptive statistics and efficiency measures developed by the authors. They found the primary causes of rework to be design error (33%), vendor error (23%), and owner changes (20%) (Georgy et al., 2005). This analysis contributes additional weight to the overall trend recognizing design errors and omissions as leading causes of change orders.

Gunduz and Hanna (2005) used the same method that Hanna et al. (2002) used to calculate productivity in Hanna's earlier studies (1999a,b). However, they expanded the detail of the previous studies by characterizing results by project size. While specific results are difficult to generalize across the three classifications of small, medium, and large, Gunduz and Hanna (2005) indicated that pre-construction activities and the amount of change generally correlated with negative impacts on productivity.

The Nassar et al. (2005) study that focused on asphalt paving documented an average 4% cost increase on asphalt projects and reported the primary cost overrun causal factors to be unpredictable addition (unforeseen site conditions), differences between the planned quantities and final needed quantities, environmental cleanup, and finally design errors. These results are in concert with the other results reviewed so far, finding design as a key causal issue of change orders.

The final effort reviewed is that of the previously cited effort of Günhan et al. (2007) investigating public school construction. Although design errors were found to be a cause of change orders, they were not a consistently high percentage of causes over the study period (Günhan et al., 2007). Günhan et al. (2007) reported unforeseen site conditions to be the only consistent source of change orders; owner changes, code compliance issues, design errors and omissions, and other changes all fluctuated at varying degrees over the study period. However, it should be noted that this finding was based on data drawn from a single school district.

Department of Defense

The specific focus of the current research effort is the analysis of U.S. Air Force MILCON projects. Past studies of MILCON and DoD work are quite comparable and provide a good source of historical information with which to compare the results of the present effort.

Rowland (1981), in the first study within the DoD to focus on change order rates, studied change orders from the Southern Division of the Naval Facilities Engineering Command (NAVFAC). By analyzing bid data collected from 19 projects using descriptive statistics, Rowland (1981) identified three significant results: change order rates increased as bid dispersion increased, change order rates increased as the size of the project increased, and change order rates were highest in commercial construction (followed by industrial and heavy construction). Rowland (1981) also highlighted the difficulties of studying change orders because of the diversity of unrelated economic factors that can affect a project (e.g., inflation, public policy, labor issues).

A subsequent Navy study utilized data collected from the Western Division of the Naval Facilities Engineering Command. Rosmond (1984) utilized a broader data set in terms of project numbers than the previous work by Rowland (1981); however, both were limited to specific geographic regions. Rosmond (1984) investigated whether or not contractors were low-bidding government contracts and attempting to use change orders to compensate for low profit margin. Using regression and analysis of variance

(ANOVA), the study tested the correlation of change order rates with a number of independent variables. No single variable, nor any combination of variables, were found to account for the change order rates within the Western Division (Rosmond, 1984), further demonstrating, as in Rowland's (1981) study, the complexity of variables affecting change rates. Rosmond (1984) particularly focused on competition measures within the bidding environment but also included geographic area, quarter of the fiscal year in which the project was awarded, and others. Interestingly, Cook's (2006) work provided contrasting results, showing both an increase in cost overruns for projects awarded in the 4th quarter and a decrease in cost overruns in a highly competitive bid environment. Cook's (2006) data, however, covers a broad geographic range and the spectrum of construction types.

A third Navy study completed in 1995 used a different approach. Instead of analyzing data to find trends, Barrientez (1995) identified known causes for change orders based on a combination of Navy guidance and industry standards used to document changes. Barrientez (1995) then surveyed 58 completed projects from Corpus Christi Naval Air Station to analyze cost and time data to determine the frequency with which a predefined set of causes occurred. A second analysis was performed to determine the frequency of known causes within various types of construction work (e.g. electrical work, mechanical work, civil work, etc.). Barrientez (1995) found the predominate source of change orders in the majority of construction types was owner changes; in projects in which owner changes were not the predominate cause for change orders, owner changes were still significant causes. Barrientez (1995) also found that design errors comprised only 5% of the total cost of change orders. This represented a significant departure from industry research in which design errors and omissions were seen as a leading cause of change.

Finally, the most recent study to address change orders within the DoD, and specifically the Air Force, was Cook's (2006) work in which he developed a predictive model of cost overruns of Air Force projects. The study found that the typical Air Force Military Construction Project (MILCON) experienced a cost overrun of 11.6% (Cook, 2006). While his research focused on contingency budgets and cost overruns, the change order is the primary vehicle by which contingency budgets are expended; therefore, Cook (2006) concluded that the cost of change orders is being underestimated.

Summation

Industry research over the last 20 years has established a relatively small set of causal factors regarding change orders, with design errors and omissions being the leading factors. However, research on military construction projects has not been as definitive. The next and final section of this chapter identifies the most common change orders causes cited by the literature.

Synthesizing Existing Research

Because of the extent and breadth of information gathered during the literature review, it was necessary to develop a method by which to synthesize a consensus of common causal factors regarding change orders. Each research effort was thus studied and the causes of change orders were identified. Because of the varied nature of the studies and language describing the causes of the change orders, generalized categories were developed to accommodate categorization of the causes. Table 1 reflects the results of this process.

Table 1. Change order roll-up.

Freq. of Occurrence	Change Order Causes
19.32%	Design Deficiencies
12.50%	User Changes
10.23%	Unforeseen Site Conditions
7.95%	Unknown, Other
6.82%	Construction Deficiencies
6.82%	Management Problems
5.68%	Weather
5.68%	Economic Conditions
4.55%	Location
4.55%	Location
3.41%	Unforeseen Environmental Site Conditions
3.41%	Safety/Labor Issues
2.27%	Under-Bidding
2.27%	Value Engineering Proposals
1.14%	Project Size
1.14%	Bid Dispersion
1.14%	Project Length
1.14%	Project Complexity

Conclusion

Existing literature has clearly demonstrated that change in projects can have a negative impact, particularly on direct costs but also indirect costs such as loss of productivity. In general terms, considering the available research, it is not unreasonable to fathom an average project direct cost increase of 10%. The impact on productivity and other indirect costs is more difficult to measure but has clearly been documented.

Minimizing these impacts is clearly in the best interest of owners, designers, and contractors.

Addressing these impacts requires an examination of their causes. A review of existing literature clearly indicates a focus on design issues as a primary cause, followed by user changes, unforeseen site conditions and a myriad of other causes (see Table 1). Fortunately, these causes are perhaps the easiest, least expensive, and most practical to address. The results of this review provide a vector by which to guide the research effort of the current study.

Chapter 3. Methodology

As discussed in Chapter 1, change orders have a large impact on the annual Military Construction (MILCON) program of the United States Air Force. Existing research outlined in Chapter 2 showed the progress past efforts have made in investigating the causes of change orders. This research effort builds on past efforts by characterizing and analyzing the nature of change orders on MILCON projects across the United States Air Force. Utilizing existing data collected from Air Force project managers, descriptive and inferential statistics were used to gauge the magnitude of change orders within the organization and detect trends or patterns of the causes of change orders with the hope that this additional insight might help improve project management performance. The research methodology consisted of four phases: data collection, initial data analysis, categorization of data, and final data analysis. Each of these phases will be discussed in this chapter.

Data Collection

In order to characterize MILCON change orders, a large amount of data on existing projects, and particularly the change orders affecting them, was required. The objective of this data collection effort was to obtain total project cost, both at the time of contract award and at financial close out, and a cause and cost for each project modification. The Air Force records this data primarily in two places: the project manager's project file and the Air Force's Automated Civil Engineer System (ACES).

Data from within Project Manager's Files

Data from the project manager's files is provided in the form of financial documentation of the project award and amendments provided by the contracting authority. Contracting personnel provide MILCON project managers two forms that document this information. The first is Standard Form (SF) 1442 which documents contract award information. The second is the SF 30 which documents any changes to the original project. Surveying these forms, particularly the SF 30, yielded the cost and cause of a given change order. The SF 1442 was necessary because it contains the original project data which was also required as part of this effort. Additionally, the SF 1442 form contains ancillary data such as location, the government agency overseeing the project, the project requester, and other information that may be analyzed for trends not directly attributable to a specific cause.

To collect the necessary data, a request was sent to the major command (MAJCOM) MILCON project managers (PMs) through the Installations and Mission Support office at Headquarters Air Force to provide the SF 1442 and SF 30s for each MILCON project considered financially completed in 2002 through 2006. The year of 2002 was chosen because, generally speaking, information for projects after that date is stored electronically. Additionally, because of the way the government contracts and pays for projects, MILCON projects are not typically financially completed for a period of time after the physical building has been completed during which all required paperwork is accomplished. The requirement for financially completed projects is necessary to screen out data that may change in the future. Although a review of SF 1442 and SF 30 forms is the preferred method of collecting data since these forms represent the original source, it would require significant efforts that are unlikely to be supported by the organizations being tasked to provide the information. Therefore, collecting the data electronically is considered the most practical option.

Data from within ACES

The ACES system is a large electronic database utilized by civil engineers to document, track, and issue reports on a number of organizational functions. Since part of the system is dedicated to project management, Civil Engineering PMs report project data to higher headquarters levels through this system. Accessing the database is accomplished via a request to a central office and the data is provided rapidly at little cost. Using data obtained from this system relies on the assumption that the system was regularly and accurately updated. It also limits the amount of information that a project manager can document by setting limits on the size of the field used to describe a change order. This requires the project manager to distill the data from the SF 30 into a description that will fit within the space provided by ACES. This decreases the fidelity of the description of change orders.

Initial Data Analysis

The purpose of the initial data analysis was to empirically detect common trends in the causes of change orders within Air Force MILCON projects. To effectively do this, the change must be carefully attributed to causes that have meaning to the organization so that the change (and cause) can be appropriately addressed. An initial list of common causes was developed from information gathered during the literature review in Chapter 2. Based upon their frequency of observation in previous research, the most common change order causal factors identified in Chapter 2 are *Design Deficiencies, Unforeseen Site Conditions, Unforeseen Environmental Site Conditions, User Changes, Unknowns,* and *Weather.* These causes are defined (see Table 3, Chapter 4) to create a standard by which change orders can be judged. This list was used as the basis for the categorization of change order causes. When less common causes identified during the literature or previously encountered causes were identified, new categories were created and added to a "watch list." The "watch list" served as a place holder for potential cause categories that may or may not be meaningful (an example of a meaningless cause would be a cause that is observed only a few times out of several thousand data points). The change order causal factor list and the watch list were the vehicles by which the categorization of the data took place.

Categorization of Data

Once a basic list of change order causes and their definitions were generated, each change order was evaluated and assigned to one of the causal factor categories. During this categorization, the geographic location and project name were hidden to guard against researcher bias. As a further measure to prevent bias, the following protocol was used to determine the cause of a given change order.

1. Read change order cause as listed on the SF 30.

2. Review the change order causal factor list and determine the appropriate category, based on the category definitions, which most closely resembles the change order cause from step 1. If a suitable causal factor is found, assign the change order to that category and proceed to step 5; if not, proceed to step 3.
3. Review the "watch list" and determine the appropriate category, based on the category definitions, which most closely resembles the change order cause from step 1. If a suitable causal factor is found, assign the change order to that category and proceed to step 5. If the cause of the change order is not on the watch list, add an appropriate category to the list, define it, and proceed to step 5; if not, proceed to step 4.
4. If no cause can be determined from the available information, classify the change order as an unknown causal factor and proceed to step 5.
5. Verify that a causal factor category has been assigned to the change order, then repeat the process for the next change order.

Once a change order was assigned to a causal factor category, it was changed only if clear evidence emerged that the initial categorization was incorrect.

Final Data Analysis

The final data analysis consisted of two steps: a descriptive characterization of the data and a statistical analysis of the data. The descriptive characterization of the data provided quantification of the costs of change in terms of cause. It also provided an anecdotal assessment of how well the Air Force is managing the data in terms of how much data could not be used due to lack of supporting information. The statistical analysis of the data provided an evaluation of the impact of each change order cause and a rank-order of the causes in terms of impact to the organization. Given the data to be collected, a single-factor, one-way analysis of variance (ANOVA) test was initially selected to evaluate the change order causal factors in terms of standardized cost, which was defined as the change order cost as a percentage of the overall project cost. Utilizing this test requires several assumptions be met: a) the data are independent and random, b) the populations have approximately normal distributions, and c) the population variances are equal (McClave, Benson, and Sincich, 2005). However, after an initial review of the data, it was determined that the data violated the normality and homogeneity of variance assumptions; therefore, the ANOVA test could not be used.

Because of the lack of normality and homogeneity of variance, this research used the Kruskal-Wallis (KW) test, which is a nonparametric median comparison test in which that data are either provided in rank order or are rank ordered by the researcher (Sheskin, 2007). This test requires that "a) the data has been randomly selected from the population, b) the data is independent, c) the dependent variable is continuous, and d) the underlying distributions from which the samples are derived are identical in shape" (Sheskin, 2007). The data met these assumptions.

The general procedure, as outlined by Sheskin (2007), includes the following steps: rank order the data, adjust rankings for any ties, sum the rankings to determine the score per group (i.e., causal factor), and calculate the test statistic. The null hypothesis for the procedure is (Sheskin, 2007): $H_0 : \theta_1 = \ldots = \theta_k$. In other words, it is hypothesized that the medians of each group are equal. The alternative hypothesis of the test is (Sheskin, 2007): H_1 : Not H_0, which hypothesizes that the medians of at least two groups differ. This is an important point of distinction; while the null hypothesis indicates that all groups are equal, the alternative hypothesis does not state that all groups differ; the alternative hypothesis states only that at least two differ (Sheskin, 2007). The test-statistic is given by:

$$H = \frac{12}{N(N+1)} \sum_{j=1}^{k} \left[\frac{\left(\sum R_j\right)^2}{n_j} \right] - 3(N+1)$$

which calculates a Chi-Square approximation where *N* is the total number of samples, *k* is the total number of groups (i.e., CO Causal Factors), R_j is the sum of the ranks for each group *j*, and n_j is the number of subjects for each group *j* (Sheskin, 2007).

Using the appropriate degrees of freedom and the level of significance chosen by the researcher, the Chi-square value is calculated or determined from the Chi-square distribution table to determine if a significant difference exists among the subject groups (Sheskin, 2007). The present research effort utilized the JMP® statistical analysis software package which includes a correction for excessive numbers of ties. This correction also provides a more conservative test of the alternative hypothesis (Sheskin, 2007). The correction is based on the number of tied scores that occur within the ranking of the data and is given by (Sheskin, 2007):

$$C = \frac{1 - \sum_{i=1}^{s} \left(t_i^3 - t_i\right)}{N^3 - N}$$

where s is the number of sets of ties, t_i is the number of tied scores in the i^{th} set of ties, and N is the total number of samples. The corrected test statistic is given by (Sheskin, 2007) as: $H_C = H/C$.

Once a statistically significant difference is shown among the change order causes, the data is examined to determine if there were differences between pairs of causes. A multiple comparison technique for large sample sizes was applied as first described by Dunn (1964) and referenced in both McClave (2005) and Sheskin (2007). This technique uses the means of the ranks of each group to calculate the minimum required difference required to show that each group is different from one another (Sheskin, 2007). The difference is calculated by (Sheskin, 2007) as:

$$CD_{KW} = z_{adj}\sqrt{\frac{N(N+1)}{12}\left(\frac{1}{n_a}+\frac{1}{n_b}\right)}$$

where N is the total number of observations, n_a and n_b are the numbers of observations in each group, and z_{adj} is a function of the number of comparisons made and the tolerance for error (Sheskin, 2007). The value for z_{adj} is taken from the normal distribution table based on the "per comparison Type I error rate (α_{PC})" (Sheskin, 2007). This error rate is controlled by the Bonferroni-Dunn method which divides the maximum acceptable error by the total number of comparisons: $\alpha_{PC} = .05/c$ where c is the total number of comparisons (Sheskin, 2007). Using the Bonferroni-Dunn method ensures that the total error introduced will not be greater than an overall α value of 0.05.

Conclusion

The methodology used four processes that collect and analyze data from existing sources of U.S. Air Force project managers. Utilizing this methodology yields an assessment of the most common causes of change within Air Force MILCON projects. This assessment will show the magnitude of each cause and statistically assess which causes have the greatest impact on projects. Chapter 4 discusses in detail each phase of this methodology as implemented.

Chapter 4. Results

The results of the methodology outlined in Chapter 3 are presented in this chapter. Discussed in detail are data collection, initial data analysis, categorization of data, and final data analysis. The chapter concludes with a summary of the results.

Data Collection

During this portion of the methodology, data was collected from two sources. The preferred approach of gathering data directly from the project manager's files had limited success. This was followed by a subsequent, successful effort to collect data from the Automated Civil Engineer System (ACES) database.

Data from within Project Manager's Files

A data request was submitted to Headquarters Air Force, Installations and Mission Support Office, tasking Major Command (MAJCOM) Military Construction (MILCON) project managers (PMs) to provide electronic copies of standard form (SF) 1442s and SF 30s of projects financially completed between 2002 and 2006. After three months with no responses, a more targeted approach was used. A list of 200 projects from the ACES database that met the criteria outlined in the original request was generated and the request for data was reissued. The resulting response rate of 16% (see Table 2 for responses) was insufficient to meet the research needs.

Table 2. Data Call Response Rate by MAJCOM

MAJCOM	Response Type	
	Electronic	Paper Copy
Air Combat Command	0	0
Air Education and Training Command	1	15
Air Force Material Command	0	0
Air Force Reserve Command	0	0
Air Force Space Command	0	0
Air Force Special Operations Command	3	0
Air Mobility Command	0	0
Pacific Air Forces	5	0
United States Air Forces in Europe	7	0
Total	16	15
Total Requested	*200*	

Several key observations were made during this data collection effort. Despite efforts within the Air Force to convert to digitally maintained documents, half of the respondents could only respond with paper copies. When PMs were contacting directly, they often stated that either the data was not readily accessible electronically or that they simply did not have it. One program manager stated that it was not policy to maintain the requested contractual data within their project files. Other managers forwarded the data request to the construction agent, typically the Army Corps of Engineers (COE). However, requiring this data to be made available for future Air Force review is not typically stipulated in MILCON project contracts; therefore, the COE representatives indicated that they did not have easy access to the data and requested additional funds to pay for the necessary staff work. While no definitive conclusion can be drawn as to why many program managers could not respond, it is clear that the data is not maintained in a manner sufficient for easy recall at a later date.

Data from within ACES

The low response rate from MAJCOM program managers posed a severe problem. Thirty-one projects did not yield a sufficient sample size from which to draw statistical conclusions. Additionally, the data was concentrated primarily in one MAJCOM, Air Education and Training Command (AETC), which would have skewed the results. Therefore, ACES data from Cook's (2006) prior research effort were used to obtain the required project information. This data consisted of MILCON projects financially completed from the years 2000 to 2004; this represented 326 projects with a total of 5,286 change orders. However, many of the ACES data fields were either incomplete or contained inconsistencies. Furthermore, 17% of the change orders lacked complete information in the following fields: Basic Low Bid amount, Change Order amount, and Change Order description. Therefore, only 278 projects, comprising 3,842 change orders, contained sufficient data. To avoid stratification between the ACES data and the contractual data contained in the SF 1442 and SF 30 forms, the 31 projects initially submitted were not used as part of the analysis.

Initial Data Analysis

The intent of this phase was to initiate a list of change order causes by which to categorize the data. This initial list is outlined in Table 2 and is comprised of the most frequently observed causes of change orders reported in the literature. Per the methodology, these factors have been subsequently defined to establish standards for classification. Discussed in the next section, an additional list was created of potential change order causal factors, which was called the Watch List.

Table 3. Defined change order causal factors observed in literature

Causal Factor	Definition
Design Deficiencies	Change orders attributed to mistakes made by design engineers and those responsible for the review of the designs
Unforeseen Site Conditions	Change orders that could not be avoided due to hidden problems that could not be detected during design
Unforeseen Environmental Site Conditions	Change orders due to unknown environmental contamination that could not be detected during design
User Changes	Change orders initiated by the user after the initial contract had been awarded
Unknown Causes	Change orders that contained data in all required fields but the data was of insufficient quality to determine a cause
Weather	Change orders due to inclement weather

Several factors identified in the literature review were not included in either the final change order causal factor list or the watch list. Although construction deficiencies were frequently identified in the literature, they were not included because they represent work that did not meet the specifications of the contract and therefore are the responsibility of the contractor. The factors of management problems, economic conditions, materials issues, safety/labor issues, bid dispersion, and project complexity were not included because the ACES data typically did not contain enough detail to attribute a change order to one of these causes. Other factors that were not included were project size and project length. Project sizes were not recorded in consistent units within the database and could not be converted to a common unit; for example, a number of projects were recorded as “1 each” as opposed to square feet or square meters. Project length data was lost as a result of the way in which data was collected from the ACES database. The final variable identified in the literature that remains unaccounted for is location. Although location information was included within the ACES data, the large number of unique bases made studying location by base infeasible. Therefore, location was investigated by MAJCOM.

Categorization of Data

The 3,842 change orders retrieved from the ACES data were imported into an Excel spreadsheet and categorized according to the change order causal factor list shown in Table 2. During this process, all data fields in the ACES data were masked except for the change order description. Additionally, the protocol outlined in Chapter 3 was used to attribute a cause to each change order. During the categorization process, the watch list of factors not identified in phase one was generated; this list is shown in Table 4. The results of the categorization process are show in Table 5.

Table 4. Change order watch list

Causal Factor	Definition
Value Engineering Proposals	Proposals made by the contract to decrease the cost of the project through the use of smart construction materials and techniques
Exercised Options	Options built into and negotiated as part of the initial contract and awarded at a later date as a change order
Scope deletion	Change orders removing scope from a project

Table 5. Results of the categorization of data

Change Order Causal Factor	# of Change Orders
Unforeseen Site Conditions	147
Unforeseen Environmental Site Conditions	82
User Change Requests	727
Value Engineering Proposals	11
Design Deficiencies	1573
Unknown Causes	810
Weather	235
Exercised Option	35
Scope Deletion	222
Total	3842

Final Data Analysis

The final data analysis utilized the data categorized in phase three to characterize change orders within the Air Force and draw conclusions about their causes. The results are presented in two parts. The first part characterizes the data collected and the second presents a statistical analysis of causal factors.

Characterization of ACES MILCON Data

This section presents a characterization of the categorized data, which consisted of the usable MILCON projects financially completed from 2000 through 2004 (provided they were entered into the ACES database). Of the original 5,286 change orders, 495 were excluded because they were not associated with MILCON projects and 949 did not contain enough information to be included in the study. Of the remaining 3,842 change orders, an additional 810 lacked sufficient information in the change order description field and were attributed to an unknown cause. An additional data point was deleted from the analysis because it occurred as the result of an extraordinary circumstance that served as an accounting correction within the government contracting system and not as a change order. Therefore, there were 3,031 change orders included in the analysis, which means that 37% or (1 – 3031/4791) of the ACES MILCON data was of insufficient quality to be included in this effort. The data is spread across the entire geography of the Air Force and encompasses every MAJCOM as shown in Figure 1.

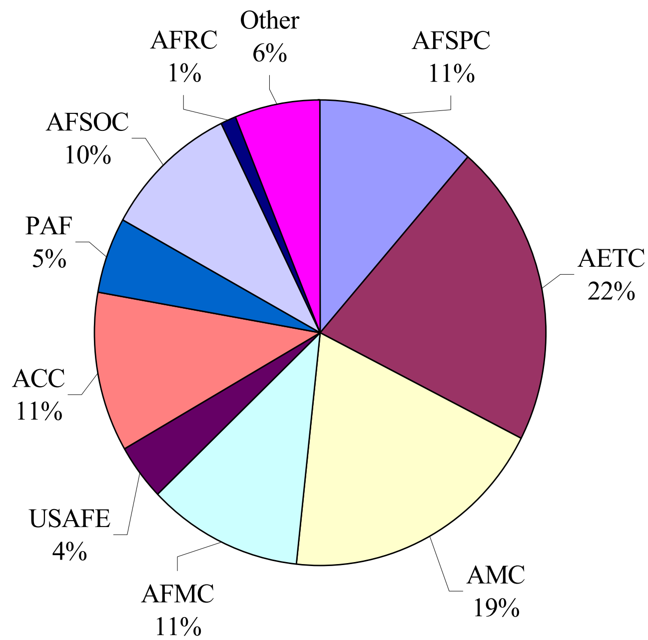


Figure 1. Change Order Distribution by Major Command

The Army Corps of Engineers (COE) administered the construction of 73% of the projects for the change orders analyzed, while the Naval Facilities Command and Air Force administered the construction on 12% and 15% of the projects, respectively. By US Code (Title 10, Subtitle A, Part IV, Chapter 169, Subchapter III, § 2851), DoD Instruction (4270.5, sec 4.3.3.1), and the Air Force Military Construction Program Management Plan (sec 3.3b); the Air Force can act as construction agent for up to 5% of the total value of the MILCON program for a given fiscal year. Prior to 2003, this was not possible. Based on anecdotal evidence, it is highly suspect that the Air Force truly executed 15% of the MILCON projects within the dataset. This is likely more representative of erroneous entries in the database.

The categorization of the data is shown in Table 6. Speaking in a strictly descriptive sense, exercised options averaged as the most expensive change orders, costing $200,000 each and were also the most time consuming, causing an average delay of 18 days per change order. Weather events (excluding disasters) caused the second most delay at an average of 17 days per change order but cost, on the average, the least at $1,700 each. There were 11 value engineering change orders that averaged $56,000 in savings per change. Finally, the remaining factors conservatively averaged $25,000 in cost and 6 days of delay per change

When considering the tabulated results in Table 6, it was clear that not all the data could be compared as planned. First, 810 samples that were attributed to unknown causes were excluded from analysis. While they serve as a metric of the ACES data system, they do not yield useful information about the nature of change orders. Second, there was an insufficient number of samples attributed to value engineering to make valid comparisons to the other causal factors. Finally, the scope deletion and exercised options categories posed a significant problem. While both may represent change order causes on paper, they may also be considered coping behaviors. Project managers in the Air Force use scope deletion to accommodate for projects that are outstripping budget constraints and use exercised options to absorb excess contingency. These causes of change orders are entirely within the project manager's control. The remaining five causal factors (unforeseen site conditions, unforeseen environmental site conditions, user change requests, design deficiencies, and weather) all represent causal factors beyond the control of the project manager.

Table 6. Change Order Tabulation by Causal Factor

Change Order Causal Factor	# of Changes	Cost ($) per Factor		Delay (days) per Factor
Unforeseen Site Conditions	147	$3,293,927		859
Unforeseen Environmental Site Conditions	82	$2,239,376		569
User Change Requests	727	$17,689,511		3759
Value Engineering Proposals	11		-$620,228	0
Design Deficiencies	1573	$39,382,507		7478
Unknown Causes	810	$24,245,281		4690
Weather	235	$392.670		4054
Exercised Bid Option	35	$6,810,601		626
Scope Deletion	222		-$5,582,969	408
Total	3842	$94,053,873	-$6,203,197	22,443

Statistical Analysis of ACES MILCON Data

The methodology outlined in Chapter 3 was implemented using a combination of the software tools JMP® and Excel®. The statistical tests were applied to the data on the basis of the change order causal factor, MAJCOM, construction agent (the organization who managed the actual construction), and year of completion. In each case, the dependent variable consisted of the standardized cost of each change order, which is the change order cost presented as a percentage of the total project cost. Each group of statistical tests is presented in three sections: the hypothesis, the results of the Kruskal-Wallis (KW) test, and the results of the Dunn ranking technique (if applicable).

Verifications of relevant assumptions are documented in the appendix. The error rate (α) is 0.05 for all tests.

Analysis of ACES MILCON Data by Change Order Causal Factor

The causal factors of *Unforeseen Site Conditions, Unforeseen Environmental Site Conditions, User Change Requests, Design Deficiencies,* and *Weather* were compared using the KW test; verification of the relevant assumptions is provided in Appendix A. The null hypothesis states that the medians of the population of each causal factor are equal; in other words, $H_0 : \theta_1 = \theta_2 = ... = \theta_k$. The alternate hypothesis is that at least two of the medians of the population of each causal factor are different where H_1 : Not H_0. The test statistic was calculated as $H_C = 430.8199$. From the Chi-Square distribution table (Sheskin, 2007), $\chi^2_{.950} = 9.49$ with a p-value < 0.0001. Therefore, the null hypothesis is rejected, which means that at least two of the change order causal factors have different median values of their populations. The Dunn test was performed and the results indicated that the median values for *Unforeseen Site Conditions, Unforeseen Environmental Site Conditions, User Changes,* and *Design Deficiencies* were higher than *Weather*. The only other significant difference was that *Unforeseen Site Conditions* had a greater impact than *User Changes*.

These results did not provide the fidelity that had been hoped for. Probable reasons for the lack of fidelity are discussed in the limitations section of Chapter 5. However, it is clear that weather has the lowest impact on projects. The other four categories can in some way be attributed to pre-construction activities. Site conditions, user changes, and design deficiencies are causes that can be addressed through increased vigilance during pre-construction activities. Therefore, the design process appears to show room for improvement. This is not unexpected and coincides with much of published literature on the subject as reported in Chapter 2.

Analysis of ACES MILCON Data by Major Command (MAJCOM)

The major commands were also compared using the KW test; verification of the relevant assumptions is provided in Appendix A. The null hypothesis states that the medians of the population of each causal factor are equal, $H_0 : \theta_1 = \theta_2 = ... = \theta_k$. The alternate hypothesis is that at least two of the medians of the population of each causal factor are different, H_1: Not H_0. The test statistic was calculated as $H_C = 61.2876$. From the Chi-Square distribution table (Sheskin, 2007), $\chi^2_{.950} = 15.51$ with a *p*-value < 0.0001. The null hypothesis is thus rejected, indicating that at least two MAJCOMs have different median values of their populations. The Dunn test was performed and the results are presented in Figure 2. The conservative nature of the KW test and subsequent Dunn test ranking did not allow for more specific results, which are shown in Figure 2.

USAFE	AFSOC	AFSPACE	AMC	AETC	ACC
AFMC			AMC	AETC	ACC
PAF				AETC	ACC
AFRC					ACC

Figure 2. Dunn Test Results – MAJCOM Rankings

USAFE, AFMC, PAF, and AFRC are not ranked, the results of the test could not conclusively show any cost difference in the median change order cost between those commands. Figure 2 shows that the median cost of change orders in USAFE was higher than the median cost of change orders in AFSOC, AFSPACE, AMC, AETC, and ACC; the median cost of change orders in AFMC was higher than the median cost of change orders in AMC, AETC and ACC; the median cost of change orders in PAF was higher than the median cost of change orders in AETC and ACC; and finally the median cost of change orders in AFRC was higher than the median cost of change orders in ACC. No ranking of the commands on the right side of the table with one another can be implied (for instance within USAFE, AFSOC is not greater than AFSPACE). Of the commands with high medians, AFMC stands out. USAFE and PAF both execute projects overseas and the data sample for AFRC was very small. While not conclusive, there is some evidence to indicate that AFMC experienced more financial impact from change orders than other commands. Interestingly, while the results on the right side of Figure 2 are not presented in rank order, it is notable that ACC was the only command that had a lower median than USAFE, AFRC, AFMC, and PAF. ACC showed a strikingly greater mean difference when compared to the other commands (see Appendix C). The results are not conclusive; however, evidence suggests that ACC may have lower cost impact from change orders as opposed to other commands.

Analysis of ACES MILCON Data by Construction Agent.

The construction agents (Army Corps of Engineers, Naval Facilities Command, and the Air Force) were also compared using the KW test; verification of assumptions is provided in Appendix A. As with the previous tests, the null hypothesis states that the medians of the population of each causal factor are equal, $H_0 : \theta_1 = \theta_2 = ... = \theta_k$. The alternate hypothesis is that at least two of the medians of the population of each causal factor are different, H_1: Not H_0. The test statistic was calculated as $H_C = 13.7245$. From the Chi-Square distribution table (Sheskin, 2007), $\chi^2_{.950} = 5.99$ with a p-value < 0.001. The null hypothesis is thus rejected, which means that at least two construction agents have different median values for their populations. The Dunn test was performed and the median of the change order costs as a percentage of total project cost was higher for the Air Force than both the Army Corps of Engineers and the Naval Facilities Command. This test is very suspect and is not considered to be valid because of the probable error discussed earlier regarding the dataset and the construction agent field. However, this test does reveal that 15% of the projects, by a fairly wide margin, had change order medians that did in fact exceed the median costs of the other two groups.

Analysis of ACES MILCON Data by Year

For the final analysis, the years of 2000 through 2004 were compared using the KW; verification of assumptions is provided in Appendix A. The null hypothesis states that the medians of the population of each causal factor are equal, $H_0 : \theta_1 = \theta_2 = ... = \theta_k$ The alternate hypothesis is that at least two of the medians of the population of each causal factor are different, H_1: Not H_0. The test statistic was calculated as $H_C = 19.2240$. From the Chi-Square distribution table (Sheskin, 2007), $\chi^2_{.950} = 9.49$ with a *p*-value < 0.0007. The null hypothesis is thus rejected, indicating that at least two years had statistically different medians. The Dunn test revealed that the year 2004 had a higher median than all other years. However, the small sample size in relative comparison to the other years makes this result somewhat suspect. Given the amount of suspect error in the dataset, it is likely that additional project data from 2004 would yield a different result.

Conclusion

Data collection was plagued by a low response rate and poor quality. When statistical analysis was applied, some useful descriptive characteristics of the population were tabulated. When the data were tested using the KW test, statistical differences were found; however, due to the low quality of the data, the differences could not be definitively ranked in most cases. The analysis does, however, suggest several courses for further investigation. The results and potential uses of the results are discussed further in Chapter 5.

Chapter 5. Conclusion

This chapter concludes the research effort with a discussion of the results, an overview of limitations that affected the work, recommendations to Air Force project managers (PMs), and some suggestions for future research.

Discussion of Results

The most profound result of this effort is the spotlight placed on the typical Air Force civil engineer's ability to capture and retain Military Construction (MILCON) project information for future use. The response rate to the initial request for project data was only 15.5% (31 of 200 projects). However, nearly half of the received project documents were in hardcopy form (15 of 31), which would seem to indicate that electronic documentation was not available. It was also noteworthy that PMs did not appear to have a standardized list of project information they maintain.

While the PMs at Air Education and Training Command, Pacific Air Forces, and Air Force Special Operations Command were responsive, other project managers either overlooked the data request or were unable to provide the data. In the case of one major command, project managers stated that they did not keep the requested records. Others claimed the Army Corps of Engineers could not provide the data without additional funding, thereby implying that they did not maintain the records themselves either. The use of data from the Automated Civil Engineer System (ACES) in place of the data sought in the initial request led to the discovery of more data housekeeping issues. When the ACES system was reviewed, 37% of the data was either nonexistent or of such poor quality that the specific change order could not be attributed to a cause.

The analysis of change order causal factors lacked enough fidelity to meet the original research goal, which was to provide PMs with a definitive rank ordered list of change order causal factors. It is clear that the most prevalent change causes are changes due to pre-construction activities. Four of the change order causes (unforeseen site conditions, unforeseen environmental site conditions, design deficiencies, and user change requests) can be attributed in some manner and in varying levels to pre-construction activities. Coupled with Cook's (2006) work showing contingency budgets are roughly half of what they should be, this seems to indicate there are systemic problems in the Air Force design process.

Among the various major commands, there is some evidence to indicate that Air Force Material Command has potentially higher median change order costs than its stateside peers; by the same token, Air Combat Command seemed to have the lower median change order costs. When considering the construction agent, the Air Force seems to have higher median change order costs than both the Army Corps of Engineers and the Naval Facilities Command. However, no specific reasons can be attributed to these observations.

Given the accuracy and completeness of the data, these results remain questionable. The methodology provided no means of checking for errors within the ACES data. For example, according to the data, 15% of the 278 MILCON projects were managed by the Air Force. While evidence is not presented as part of this effort, this statistic seems unreasonably high based on anecdotal experience and suggests that the data is not accurately and/or consistently entered into ACES. Unfortunately, the quality of the ACES data adversely impacts the results and is a severe limitation.

Limitations

This research effort was primarily limited by the quality of the data, which was considered strongly suspect for a number of reasons. Of the original 5,286 change orders, 495 were excluded because they were incorrectly associated with MILCON projects, 949 did not contain enough information to be included in the study, and 810 lacked sufficient information in the change order description field. In summary, 37% of the ACES MILCON data was of insufficient quality to be included. The methodology was not designed, nor did it provide for, error checking of the ACES data. The quality of the data thus led to the use of the conservative Kruskal-Wallis test for the statistical analysis. Utilizing contractual documents would have yielded results of higher fidelity and quality; it would have also greatly minimized the occurrences of errors. Higher quality data would perhaps have allowed the use of different testing techniques that would have provided higher fidelity within the results.

Even with perfect data though, a cause still had to be subjectively attributed to each change order. Within database systems such as ACES, and to a lesser extent even the contract documents, there is not a standardized way of reporting the cause of a change order. Therefore, the data is subject to some degree of bias from the researcher. The change order description field often contains a single, short sentence that must be used to attribute the change to a cause. Twenty-one percent of the change orders with descriptions were excluded because they could not be attributed to a cause.

These results clearly demonstrate that the Air Force does not have an effective means of capturing and recalling project data on change orders. As noted in the Barrientez study (1995), the Navy uses a standardized set of change order causes in their method of project documentation. The Air Force should perhaps investigate the possibility of incorporating a similar standardized reporting system within ACES.

Recommendations

This research has generated two primary recommendations for Air Force MILCON project managers. First, pre-construction activities seem to contribute the most to cost overruns as the result of change orders. Therefore, project managers should take a careful look at how their design review processes are accomplished. Any means by which the process can be strengthened can only improve project performance. Second, the results of this research indicate that historical project information is not easily accessible (or even available) and is generally of poor quality. However, without historical information, it is difficult to identify where past mistakes were made. Therefore, it is imperative that base-level PMs be educated on the importance of tracking historical data and the insight it can provide.

On a broader scale, the major command program managers and Air Force leadership should consider some type of management plan for historical project information that makes it easily accessible. Presently, the information that is contained in the ACES database is relatively inaccessible to the local PM by the complicated nature of the report retrieval software. If local PMs found the ACES system more useful in their day-to-day jobs, there would be more incentive to input and maintain the accuracy of the data, thereby benefiting both parties.

Future Research

This effort has generated a number of interesting potential lines of investigation. Were this study to be repeated, perhaps a better strategy would be to select a representative sample of bases and analyze MILCON work at each base comprehensively. It is clear that the cost overrun data that is presently available is of inadequate quality to definitively identify any causal trends.

Among the major commands, Air Combat Command seems to have a lower median change order cost compared with the other commands. What is Air Combat Command doing differently that other commands when it comes to the management of MILCON projects? By the same token, why does Air Force Material Command seem to have higher median change order costs?

What are the systematic problems within the Air Force design process? It seems clear that the design process and other pre-construction activities can be improved to some degree. Where is the process weak and what are the best strategies to strengthen it? Closely associated with these processes, project management training and processes could prove valuable, particularly by focusing on pre-construction activities.

Additionally, research considering the type and level of cost management most appropriate to the Air Force would be beneficial. What type of historical project information is used by the private sector and are similar methods applicable to the Air Force? What changes could be made to the ACES system to increase the quality of the data it captures? This effort has made it clear that the Air Force is underutilizing a large pool of potentially valuable data. How can the Air Force tap this resource and effectively exploit the data to improve project performance?

Finally, the data used by the present effort is somewhat obsolete, focusing on projects from 2000 to 2004. With each passing year, more data becomes available. Future efforts aimed at improving the methodology used in this research and focusing on the intricacies of ACES data should yield better results with higher fidelity.

Conclusion

This research represents a snapshot in time from 2000 to 2004. It is subject to the weaknesses of the limitations of the available data. Therefore, very conservative statistical testing was used to analyze the data. The results indicate that pre-construction activities (unforeseen site conditions, unforeseen environmental site conditions, user changes, and design deficiencies) are the major contributors to cost overrun on MILCON projects, which is further supported by other research reported in the literature. Consequently, the Air Force should focus improvement efforts on pre-construction activities (i.e., the design and design review processes).

Appendices

A. Verification of Assumptions

B. JMP® Output

C. Dunn Results

Appendix A.

Analysis of ACES MILCON Data by CO Causal Factor

a) The data has been randomly selected from the population

The data consists of the entire useable population of the data

b) The data is independent

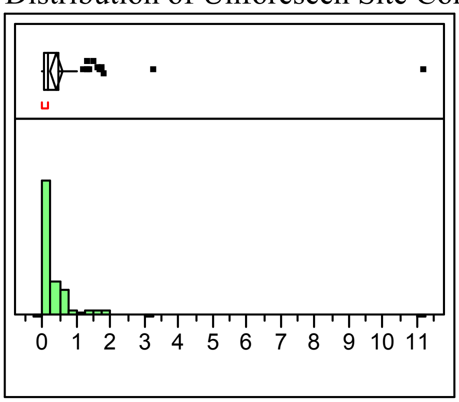
Typically change orders on one project do not affect another. Additionally, the change orders within a project are not typically dependent upon one another.

c) The dependant variable is continuous

Change order cost is a continuous variable

d) The underlying distributions from which the samples are derived are identical in shape.

Distribution of Unforeseen Site Conditions



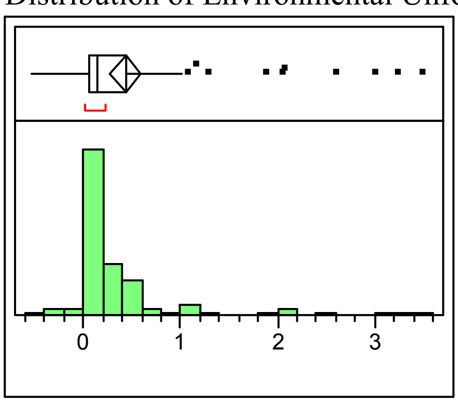
Quantiles

100.0%	maximum	11.22
99.5%		11.22
97.5%		1.77
90.0%		0.81
75.0%	quartile	0.47
50.0%	median	0.15
25.0%	quartile	0.05454
10.0%		0.01965
2.5%		0.00
0.5%		-0.0059
0.0%	minimum	-0.0059

Moments

Mean	0.4109256
Std Dev	1.0132212
Std Err Mean	0.0835691
upper 95% Mean	0.576087
lower 95% Mean	0.2457642
N	147

Distribution of Environmental Unforeseen Site Conditions



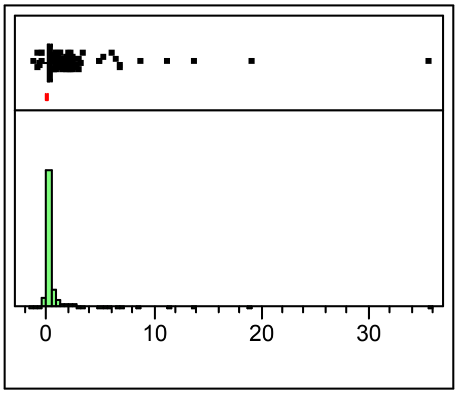
Quantiles

100.0%	maximum	3.495
99.5%		3.495
97.5%		3.226
90.0%		1.244
75.0%	quartile	0.448
50.0%	median	0.148
25.0%	quartile	0.053
10.0%		0.013
2.5%		-0.318
0.5%		-0.534
0.0%	minimum	-0.534

Moments

Mean	0.4293296
Std Dev	0.7572734
Std Err Mean	0.0836269
upper 95% Mean	0.5957208
lower 95% Mean	0.2629384
N	82

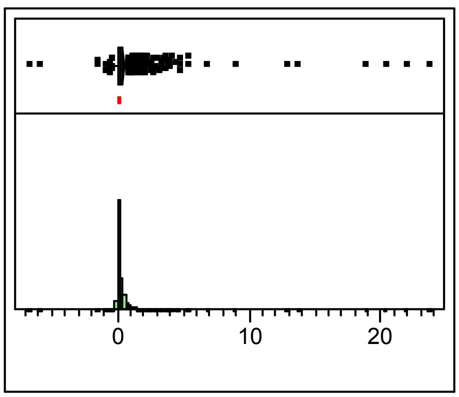
Distribution of User Change Requests



Quantiles		
100.0%	maximum	35.70
99.5%		12.09
97.5%		2.73
90.0%		0.90
75.0%	quartile	0.31
50.0%	median	0.09995
25.0%	quartile	0.02939
10.0%		0.00
2.5%		-0.17
0.5%		-0.72
0.0%	minimum	-1.27

Moments	
Mean	0.4560866
Std Dev	1.812697
Std Err Mean	0.0672292
upper 95% Mean	0.5880734
lower 95% Mean	0.3240997
N	727

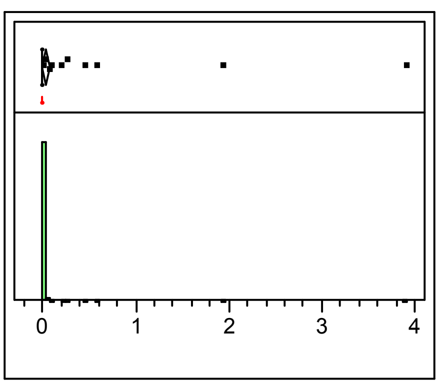
Distribution of User Design Deficiencies



Quantiles		
100.0%	maximum	23.67
99.5%		7.12
97.5%		2.52
90.0%		0.84
75.0%	quartile	0.33
50.0%	median	0.13
25.0%	quartile	0.03857
10.0%		0.0077
2.5%		-0.12
0.5%		-0.70
0.0%	minimum	-6.64

Moments	
Mean	0.3866018
Std Dev	1.354586
Std Err Mean	0.0341541
upper 95% Mean	0.4535941
lower 95% Mean	0.3196095
N	1573

Distribution of Weather



Quantiles		
100.0%	maximum	3.9092
99.5%		3.5561
97.5%		0.2082
90.0%		0.0000
75.0%	quartile	0.0000
50.0%	median	0.0000
25.0%	quartile	0.0000
10.0%		0.0000
2.5%		0.0000
0.5%		0.0000
0.0%	minimum	0.0000

Moments	
Mean	0.0325055
Std Dev	0.2887016
Std Err Mean	0.0188328
upper 95% Mean	0.0696091
lower 95% Mean	-0.004598
N	235

Analysis of ACES MILCON Data by Major Command (MAJCOM)

a) The data has been randomly selected from the population

The data consists of the entire useable population of the data

b) The data is independent

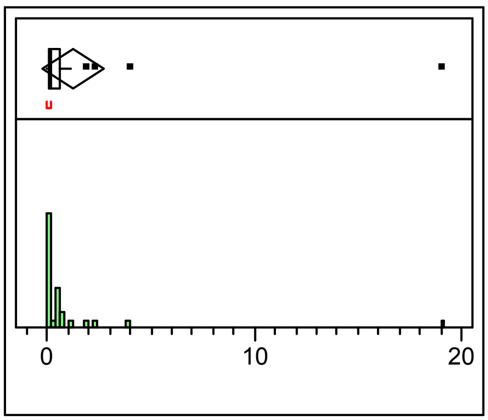
Typically change orders on one project do not affect another. Additionally, the change orders within a project are not typically dependent upon one another.

c) The dependant variable is continuous

Change order cost is a continuous variable

d) The underlying distributions from which the samples are derived are identical in shape.

Distribution of Air Force Reserve Command (AFRC)



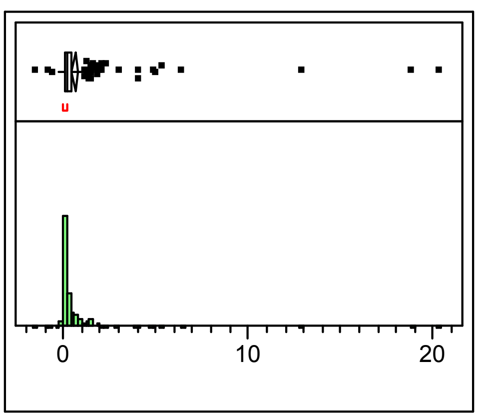
Quantiles

100.0%	maximum	19.036
99.5%		19.036
97.5%		19.036
90.0%		2.630
75.0%	quartile	0.607
50.0%	median	0.157
25.0%	quartile	0.075
10.0%		0.000
2.5%		0.000
0.5%		0.000
0.0%	minimum	0.000

Moments

Mean	1.2360305
Std Dev	3.664728
Std Err Mean	0.7052772
upper 95% Mean	2.6857486
lower 95% Mean	-0.213688
N	27

Distribution of Air Force Material Command (AFMC)



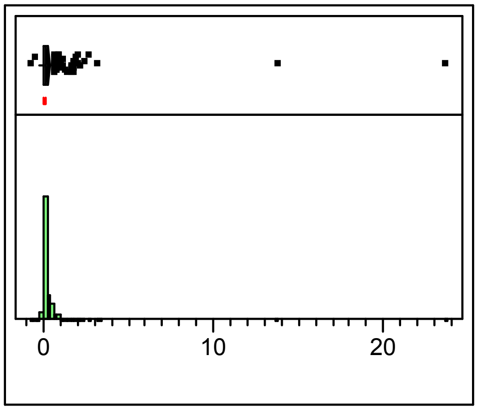
Quantiles

100.0%	maximum	20.36
99.5%		19.70
97.5%		4.70
90.0%		1.39
75.0%	quartile	0.49
50.0%	median	0.17
25.0%	quartile	0.04094
10.0%		0.00
2.5%		-0.16
0.5%		-1.23
0.0%	minimum	-1.52

Moments

Mean	0.6147893
Std Dev	1.9564418
Std Err Mean	0.1160935
upper 95% Mean	0.8433055
lower 95% Mean	0.386273
N	284

Distribution of Air Education & Training Command (AETC)



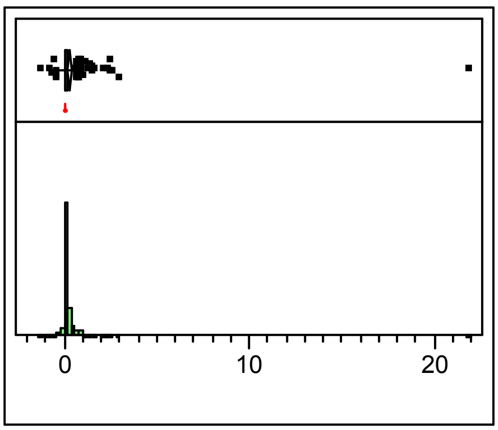
Quantiles

100.0%	maximum	23.67
99.5%		3.11
97.5%		1.71
90.0%		0.59
75.0%	quartile	0.25
50.0%	median	0.08947
25.0%	quartile	0.01147
10.0%		0.00
2.5%		-0.0372
0.5%		-0.26
0.0%	minimum	-0.69

Moments

Mean	0.2746988
Std Dev	1.1350194
Std Err Mean	0.0448656
upper 95% Mean	0.3628006
lower 95% Mean	0.186597
N	640

Distribution of Air Combat Command (ACC)



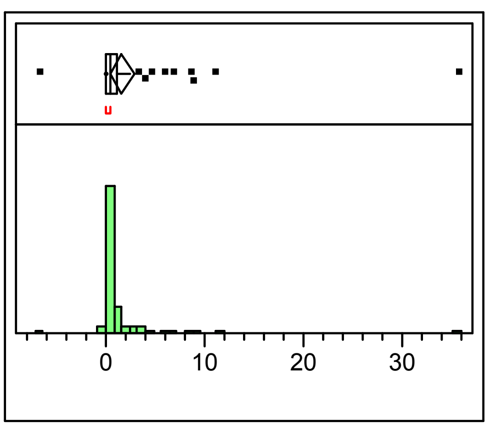
Quantiles

100.0%	maximum	21.93
99.5%		10.37
97.5%		1.65
90.0%		0.63
75.0%	quartile	0.22
50.0%	median	0.0728
25.0%	quartile	0.00205
10.0%		0.00
2.5%		-0.32
0.5%		-0.98
0.0%	minimum	-1.27

Moments

Mean	0.2715122
Std Dev	1.2912975
Std Err Mean	0.0720732
upper 95% Mean	0.4133094
lower 95% Mean	0.129715
N	321

Distribution of United States Air Forces in Europe (USAFE)



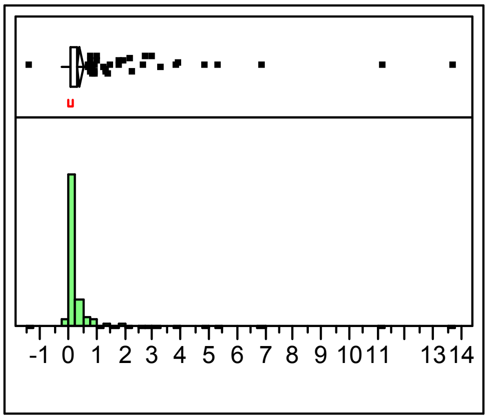
Quantiles

100.0%	maximum	35.70
99.5%		35.70
97.5%		18.55
90.0%		4.93
75.0%	quartile	1.09
50.0%	median	0.37
25.0%	quartile	0.05962
10.0%		0.00
2.5%		-2.01
0.5%		-6.64
0.0%	minimum	-6.64

Moments

Mean	1.6406586
Std Dev	4.9002945
Std Err Mean	0.5986663
upper 95% Mean	2.8359344
lower 95% Mean	0.4453829
N	67

Distribution of Air Force Special Operations Command (AFSOC)



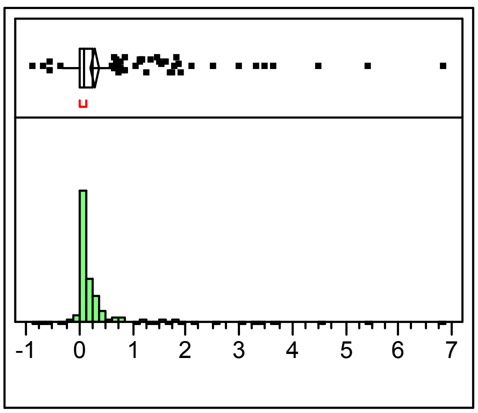
Quantiles

100.0%	maximum	13.67
99.5%		12.43
97.5%		3.52
90.0%		0.81
75.0%	quartile	0.30
50.0%	median	0.09591
25.0%	quartile	0.03022
10.0%		0.00
2.5%		-0.0531
0.5%		-0.83
0.0%	minimum	-1.45

Moments

Mean	0.4145443
Std Dev	1.2638198
Std Err Mean	0.0729667
upper 95% Mean	0.5581376
lower 95% Mean	0.270951
N	300

Distribution of Air Force Space Command (AFSPC)



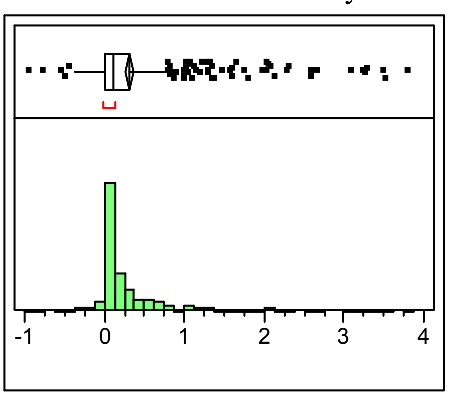
Quantiles

100.0%	maximum	6.840
99.5%		5.940
97.5%		2.441
90.0%		0.751
75.0%	quartile	0.263
50.0%	median	0.096
25.0%	quartile	0.028
10.0%		0.00565
2.5%		-0.161
0.5%		-0.748
0.0%	minimum	-0.872

Moments

Mean	0.3085845
Std Dev	0.7429431
Std Err Mean	0.0410848
upper 95% Mean	0.3894094
lower 95% Mean	0.2277596
N	327

Distribution of Air Mobility Command (AMC)



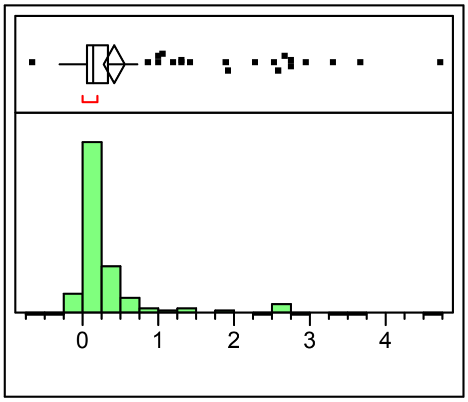
Quantiles

100.0%	maximum	3.808
99.5%		3.504
97.5%		2.175
90.0%		0.813
75.0%	quartile	0.325
50.0%	median	0.101
25.0%	quartile	0.022
10.0%		0.000
2.5%		-0.167
0.5%		-0.645
0.0%	minimum	-0.961

Moments

Mean	0.3033024
Std Dev	0.5839619
Std Err Mean	0.0259603
upper 95% Mean	0.3543059
lower 95% Mean	0.252299
N	506

Distribution of Pacific Air Forces (PAF)



Quantiles

100.0%	maximum	4.712
99.5%		4.712
97.5%		3.010
90.0%		1.278
75.0%	quartile	0.337
50.0%	median	0.143
25.0%	quartile	0.051
10.0%		0.000
2.5%		-0.209
0.5%		-0.656
0.0%	minimum	-0.656

Moments

Mean	0.4184923
Std Dev	0.795228
Std Err Mean	0.0647147
upper 95% Mean	0.5463625
lower 95% Mean	0.2906221
N	151

Analysis of ACES MILCON Data by Construction Agent

a) The data has been randomly selected from the population

The data consists of the entire useable population of the data

b) The data is independent

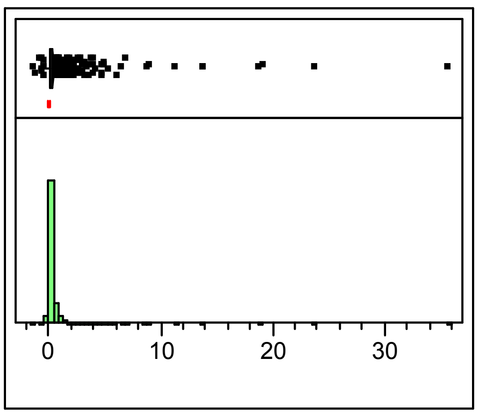
Typically change orders on one project do not affect another. Additionally, the change orders within a project are not typically dependent upon one another.

c) The dependant variable is continuous

Change order cost is a continuous variable

d) The underlying distributions from which the samples are derived are identical in shape.

Distribution of Army Corps of Engineers (COE)



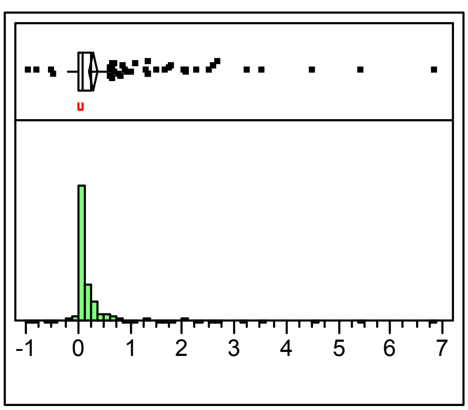
Quantiles

100.0%	maximum	35.70
99.5%		6.74
97.5%		2.10
90.0%		0.75
75.0%	quartile	0.28
50.0%	median	0.09919
25.0%	quartile	0.02208
10.0%		0.00
2.5%		-0.0582
0.5%		-0.49
0.0%	minimum	-1.45

Moments

Mean	0.3563464
Std Dev	1.372306
Std Err Mean	0.0303388
upper 95% Mean	0.4158445
lower 95% Mean	0.2968483
N	2046

Distribution of Naval Facilities Command (NAVFC)



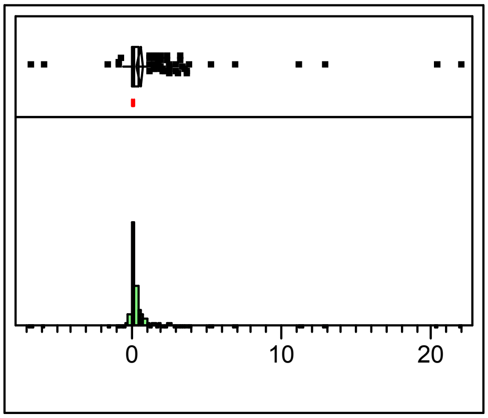
Quantiles

100.0%	maximum	6.840
99.5%		5.968
97.5%		2.486
90.0%		0.644
75.0%	quartile	0.254
50.0%	median	0.086
25.0%	quartile	0.025
10.0%		0.000
2.5%		-0.133
0.5%		-0.861
0.0%	minimum	-0.961

Moments

Mean	0.2899613
Std Dev	0.7262409
Std Err Mean	0.0404091
upper 95% Mean	0.3694606
lower 95% Mean	0.2104621
N	323

Distribution of Air Force Managed Projects (AF)



Quantiles

100.0%	maximum	21.93
99.5%		20.39
97.5%		3.51
90.0%		1.47
75.0%	quartile	0.46
50.0%	median	0.17
25.0%	quartile	0.03478
10.0%		0.00
2.5%		-0.37
0.5%		-5.91
0.0%	minimum	-6.64

Moments

Mean	0.5574867
Std Dev	1.9391857
Std Err Mean	0.097571
upper 95% Mean	0.7493117
lower 95% Mean	0.3656618
N	395

Analysis of ACES MILCON Data by Year

a) The data has been randomly selected from the population

The data consists of the entire useable population of the data

b) The data is independent

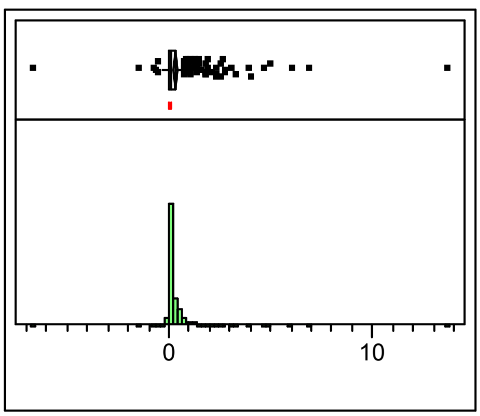
Typically change orders on one project do not affect another. Additionally, the change orders within a project are not typically dependent upon one another.

c) The dependant variable is continuous

Change order cost is a continuous variable

d) The underlying distributions from which the samples are derived are identical in shape.

Distribution of 2000 Projects



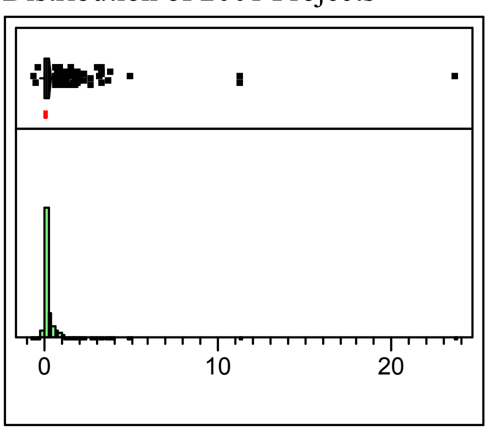
Quantiles

100.0%	maximum	13.72
99.5%		5.79
97.5%		2.38
90.0%		0.70
75.0%	quartile	0.29
50.0%	median	0.11
25.0%	quartile	0.02729
10.0%		0.00
2.5%		-0.0844
0.5%		-0.75
0.0%	minimum	-6.64

Moments

Mean	0.314635
Std Dev	0.9106
Std Err Mean	0.036024
upper 95% Mean	0.385376
lower 95% Mean	0.24389
N	63

Distribution of 2001 Projects



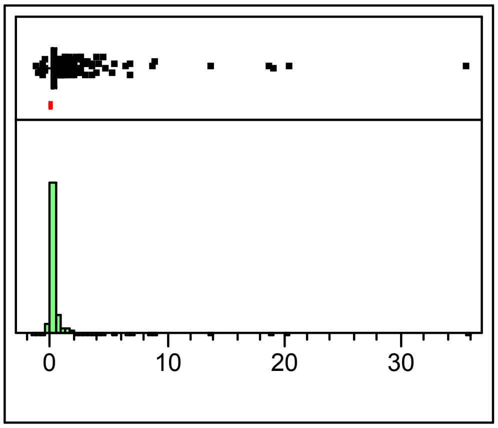
Quantiles

100.0%	maximum	23.67
99.5%		4.91
97.5%		1.92
90.0%		0.73
75.0%	quartile	0.27
50.0%	median	0.09475
25.0%	quartile	0.02282
10.0%		0.00
2.5%		-0.0452
0.5%		-0.30
0.0%	minimum	-0.68

Moments

Mean	0.3192754
Std Dev	1.1191893
Std Err Mean	0.0396189
upper 95% Mean	0.3970451
lower 95% Mean	0.2415058
N	798

Distribution of 2002 Projects



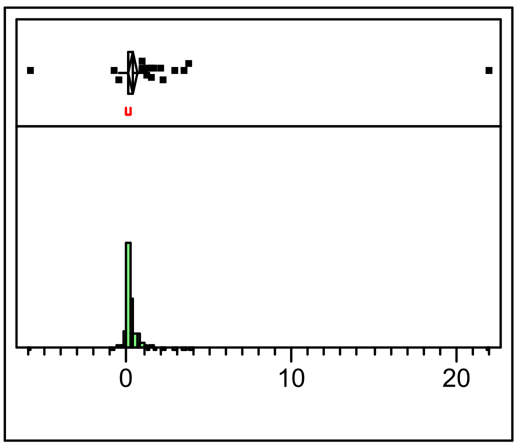
Quantiles

100.0%	maximum	35.70
99.5%		11.37
97.5%		2.64
90.0%		0.84
75.0%	quartile	0.29
50.0%	median	0.10
25.0%	quartile	0.02184
10.0%		0.00
2.5%		-0.15
0.5%		-0.62
0.0%	minimum	-1.27

Moments

Mean	0.4299581
Std Dev	1.7099225
Std Err Mean	0.0516501
upper 95% Mean	0.5313025
lower 95% Mean	0.3286138
N	1096

Distribution of 2003 Projects



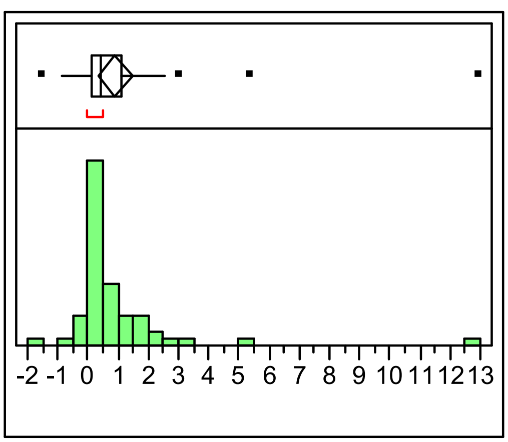
Quantiles

100.0%	maximum	21.93
99.5%		21.93
97.5%		2.62
90.0%		0.77
75.0%	quartile	0.36
50.0%	median	0.13
25.0%	quartile	0.01431
10.0%		-0.0357
2.5%		-0.42
0.5%		-5.89
0.0%	minimum	-5.89

Moments

Mean	0.3817017
Std Dev	1.7801896
Std Err Mean	0.1330576
upper 95% Mean	0.6442751
lower 95% Mean	0.1191283
N	179

Distribution of 2004 Projects



Quantiles

100.0%	maximum	12.89
99.5%		12.89
97.5%		10.43
90.0%		2.35
75.0%	quartile	1.12
50.0%	median	0.40
25.0%	quartile	0.09765
10.0%		-0.058
2.5%		-1.31
0.5%		-1.52
0.0%	minimum	-1.52

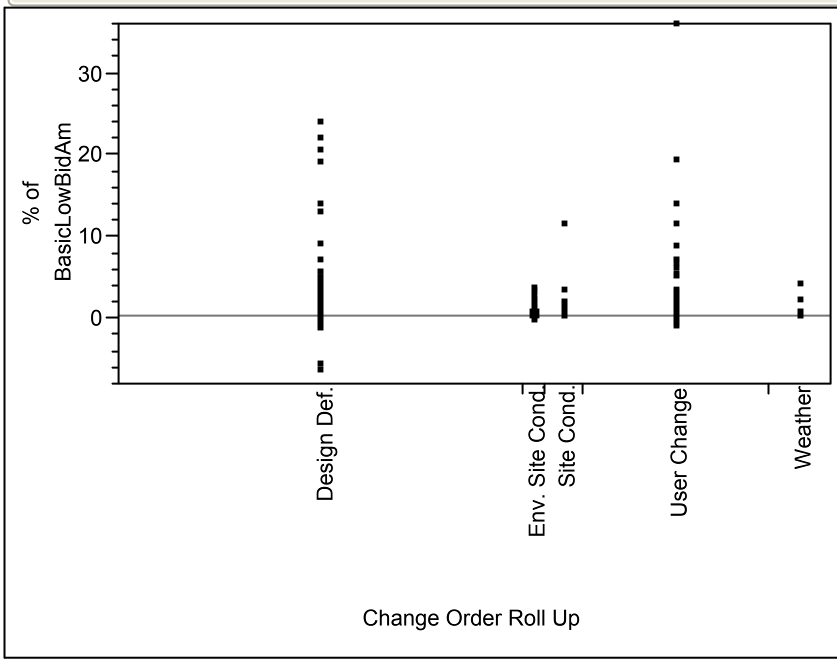
Moments

Mean	0.9145536
Std Dev	1.9926381
Std Err Mean	0.2763292
upper 95% Mean	1.4693076
lower 95% Mean	0.3597996
N	52

Appendix B.

Kruskal-Wallis ANOVA Test Results by Change Order Causal Factors

Oneway Analysis of % of BasicLowBidAm By Change Order Roll Up



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

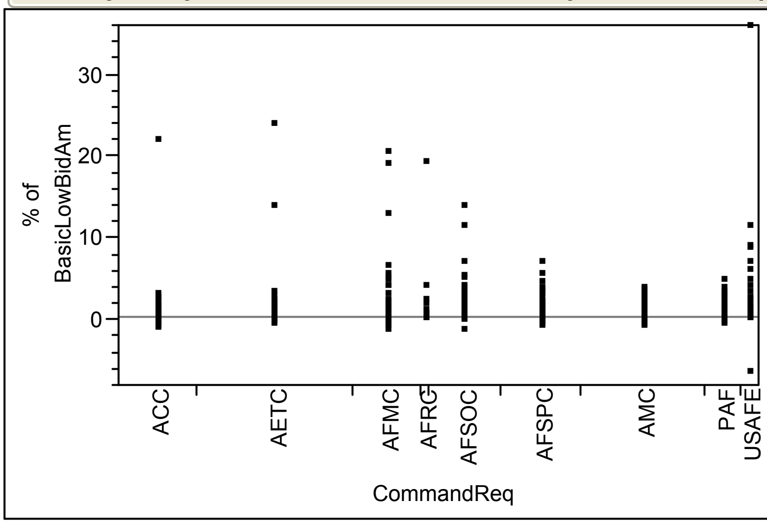
Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Design Def.	1573	2341493	1488.55	8.034
Env. Site Cond.	82	132228	1612.53	2.651
Site Cond.	147	236925	1611.73	3.581
User Change	727	1025039	1409.96	1.081
Weather	235	85546.0	364.03	-20.464

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
430.8199	4	<.0001*

Kruskal-Wallis ANOVA Test Results by Major Command (MAJCOM)

Oneway Analysis of % of BasicLowBidAm By CommandReq



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

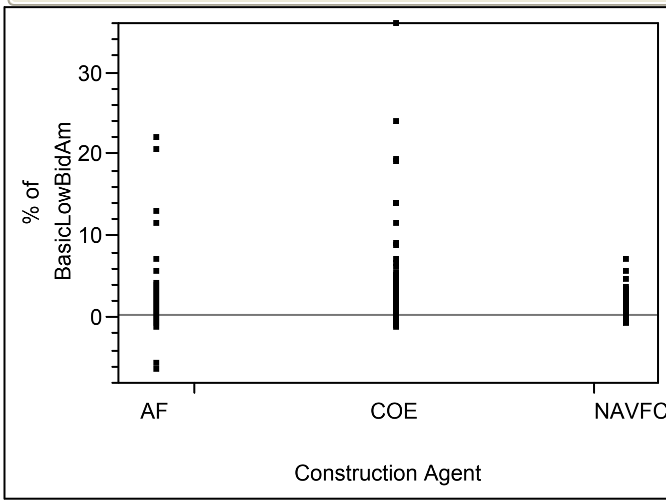
Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
ACC	321	374910	1167.94	-3.640
AETC	640	785474	1227.30	-3.256
AFMC	284	419235	1476.18	3.871
AFRC	27	44401.5	1644.50	2.294
AFSOC	300	397249	1324.16	0.296
AFSPC	327	424931	1299.48	-0.320
AMC	506	661625	1307.56	-0.147
PAF	151	219755	1455.33	2.397
USAFE	67	113799	1698.49	4.234

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
61.2876	8	<.0001*

Kruskal-Wallis ANOVA Test Results by Construction Agent

Oneway Analysis of % of BasicLowBidAm By Construction Agent



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

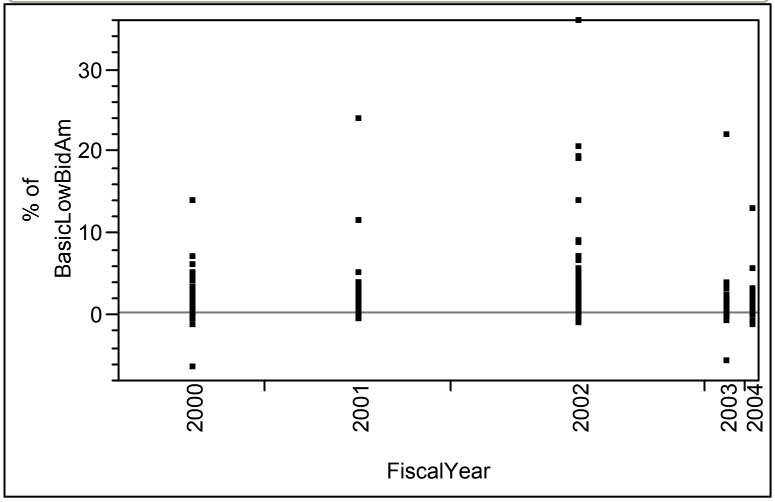
Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
AF	395	598899	1516.20	3.599
COE	2046	2794707	1365.94	-1.843
NAVFC	323	427624	1323.91	-1.405

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
13.7245	2	0.0010*

Kruskal-Wallis ANOVA Test Results by Year

Oneway Analysis of % of BasicLowBidAm By FiscalYear



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
2000	639	883280	1382.28	-0.008
2001	798	1074858	1346.94	-1.493
2002	1096	1514572	1381.91	-0.032
2003	179	252638	1411.39	0.501
2004	52	95883.0	1843.90	4.211

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
19.2240	4	0.0007*

Appendix C.

Dunn Test Results - Change Order Causal Factors

	N	Rank Sum	Rank Mean
Env. Site Cond.	82	132227.5	1612.53049
Site Cond.	147	236925	1611.73469
Design Def.	1573	2341493	1488.55245
User Change	727	1025038.5	1409.95667
Weather	235	85546	364.025532

N	2764
α	0.05
# of comparisons - c	10
α/c	0.005
zadj	2.5758

Comparison		Mean Diff	Req Diff	
Env. Site Cond.	Site Cond.	0.7958	283.3317	
Env. Site Cond.	Design Def.	123.9780	232.8471	
Env. Site Cond.	User Change	202.5738	239.4656	
Env. Site Cond.	Weather	1248.5050	263.6525	TRUE
Site Cond.	Design Def.	123.1822	177.2900	
Site Cond.	User Change	201.7780	185.8972	TRUE
Site Cond.	Weather	1247.7092	216.1634	TRUE
Design Def.	User Change	78.5958	92.1882	
Design Def.	Weather	1124.5269	143.7620	TRUE
User Change	Weather	1045.9311	154.2515	TRUE

Dunn Test Results - Major Command (MAJCOM)

	N	Rank Sum	Rank Mean
USAFE	67	113799	1698.493
AFRC	27	44401.5	1644.5
AFMC	284	419234.5	1476.178
PAF	151	219754.5	1455.328
AFSOC	300	397248.5	1324.162
AMC	506	661624.5	1307.558
AFSPC	327	424930.5	1299.482
AETC	640	785473.5	1227.302
ACC	321	374909.5	1167.942

N	2623
α	0.05
# of comparisons - c	36
α/c	0.0014
zadj	2.9913

Comparison		Mean Diff	Req Diff	
USAFE	AFRC	53.9925	516.4133	
USAFE	AFMC	222.3147	307.6874	
USAFE	PAF	243.1647	332.5486	
USAFE	AFSOC	374.3309	306.1172	TRUE
USAFE	AMC	390.9342	294.5218	TRUE
USAFE	AFSPC	399.0109	303.8013	TRUE
USAFE	AETC	471.1902	290.8942	TRUE
USAFE	ACC	530.5502	304.2837	TRUE
AFRC	AFMC	168.3222	456.2385	
AFRC	PAF	189.1722	473.3609	
AFRC	AFSOC	320.3383	455.1810	
AFRC	AMC	336.9417	447.4651	
AFRC	AFSPC	345.0184	453.6267	
AFRC	AETC	417.1977	445.0859	
AFRC	ACC	476.5576	453.9499	TRUE
AFMC	PAF	20.8500	228.1654	
AFMC	AFSOC	152.0162	187.5596	
AFMC	AMC	168.6195	167.9701	TRUE
AFMC	AFSPC	176.6962	183.7555	
AFMC	AETC	248.8755	161.5249	TRUE
AFMC	ACC	308.2355	184.5520	TRUE
PAF	AFSOC	131.1661	226.0434	
PAF	AMC	147.7695	210.0737	
PAF	AFSPC	155.8462	222.8971	
PAF	AETC	228.0255	204.9569	TRUE
PAF	ACC	287.3854	223.5542	TRUE
AFSOC	AMC	16.6034	165.0762	
AFSOC	AFSPC	24.6800	181.1140	
AFSOC	AETC	96.8593	158.5134	
AFSOC	ACC	156.2193	181.9221	
AMC	AFSPC	8.0766	160.7408	
AMC	AETC	80.2560	134.7658	
AMC	ACC	139.6159	161.6508	
AFSPC	AETC	72.1793	153.9934	
AFSPC	ACC	131.5393	177.9975	
AETC	ACC	59.3600	154.9430	

Dunn Test Results - Construction Agent

	N	Rank Sum	Rank Mean
AF	395	598899	1516.2
COE	2046	2794707	1365.93695
NAVFC	323	427624	1323.91331

N	2764
α	0.05
# of comparisons - c	3
α/c	0.0167
zadj	2.1280

Comparison		Mean Diff	Req Diff	
AF	COE	150.2631	93.3339	TRUE
AF	NAVFC	192.2867	127.3999	TRUE
COE	NAVFC	42.0236	101.6799	

Dunn Test Results – Year

	n	Rank Sum	Rank Mean
2004	52	95883	1843.90385
2003	179	252638	1411.38547
2000	639	883280	1382.28482
2002	1096	1514571.5	1381.9083
2001	798	1074857.5	1346.93922

N	2764
α	0.05
# of comparisons - c	10
α/c	0.005
zadj	2.5758293

Comparison		Mean Diff	Req Diff	
2004	2003	432.51838	323.83	TRUE
2004	2000	461.61903	296.44	TRUE
2004	2002	461.99555	291.75	TRUE
2004	2001	496.96463	294.20	TRUE
2003	2000	29.10065	173.84	
2003	2002	29.47717	165.72	
2003	2001	64.44625	170.01	
2000	2002	0.37652	102.31	
2000	2001	35.3456	109.12	
2002	2001	34.96908	95.66	

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14. ABSTRACT
Change orders are used by project managers of construction projects to account for unplanned for events. This may include everything from weather events to last minute changes requested by the user . This effort analyzes data from the U.S. Air Force military construction program to find the major causes of change orders. The data is also analyzed to find trends over time, by construction agent, and by major command to detect possible trends.

Design deficiencies are found to be the most common cause of change orders however; the data from the military database is insufficient to determine a conclusive statistical ranking. Evidence is discovered to suggest one major command may have a higher cost per change order than the others, but it is not conclusive.

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