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Analysis of Military Construction COST GROWTH in USAF MAJOR DEFENSE ACQUISITION PROGRAMS

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This study uses descriptive and inferential statistics to identify cost growth of military construction (MILCON) at the programmatic level, while bridging the gap between Selected Acquisition Report (SAR) estimates and actual project costs. Findings of this study aid the cost community with appropriate allocation of resources in developing these estimates. Overall, Major Defense Acquisition Programs (MDAP) appear to experience more negative growth (cost savings) in MILCON estimates on reviewed SARs—typically less than 0.2% of the total program cost. SAR estimates became more accurate from the first to last SAR in comparison to the total MILCON programmed for all projects within a program. However, the last SAR's median MILCON cost estimate was approximately $31 million underestimated on projects currently authorized and appropriated for MDAPs. Preliminary research was restricted to 32 programs of which only 10 had authorized and accessible projects for comparison. Initial results suggest building on this exploratory analysis.

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A myriad of factors within and outside of the Department of Defense (DoD)'s control can affect the differences often reported between initial cost estimates and final costs of military construction (MILCON) projects. However, recent MILCON projects with cost overruns have raised congressional concerns regarding the quality of DoD MILCON cost estimating practices, emphasizing the importance of an accurate cost estimate (Government Accountability Office [GAO], 2018). MILCON cost overruns are the increase of actual funds required to complete a project that has already been authorized and appropriated for execution at a lower budgetary level. In contrast, MILCON cost growth refers to the increase in cost estimates for a project or program over time (a program can consist of several projects); it can also represent a positive difference between an estimate at a given time and actual costs. Although previous studies have focused on MILCON cost overruns for projects, there appears to be no published studies documenting MILCON cost growth at a programmatic level. This article addresses this shortfall and investigates whether similar MILCON cost overruns occur at the program level.

Background

When the U.S. Air Force (USAF) acquires new programs, MILCON project requirements often accompany an MDAP, or Major Defense Acquisition Program (2017). By statute enacted in 2017 (10 U.S.C. § 2430), MDAPs are categorized as Acquisition Category I (ACAT, 2018) programs if they meet any of the following threshold criteria:

1. Total eventual expenditure of research, development, test and evaluation costs greater than $480 million (fiscal year 2014 constant dollars)
2. Total eventual expenditure of procurement costs greater than $2.79 billion (fiscal year 2014 constant dollars)
3. Specifically designated by milestone decision authority as special interest

All MDAPs are required to submit a periodic status report to Congress containing cost, schedule, and technical information; this report is called the Selected Acquisition Report (2018) and is prepared by each respective program office. The annual reporting for a particular program may be terminated by the Under Secretary of Defense (Acquisition and

Sustainment) when 90% of expected production deliveries have been made or planned acquisition expense has been disbursed (SAR, 2018). Until such time, reporting must continue periodically.

Title 10 U.S.C. § 2432 (2010) and Air Force Instruction (AFI) 32-1021 (USAF, 2016) mandate that all anticipated system-specific MILCON costs be estimated in every SAR for all MDAPs, if applicable (SAR, 2010). Project cost estimates are typically prepared by civil engineer units at bases or headquarters where new facilities are expected throughout the life of the program acquisition. The program office is responsible for submitting an accumulated programmatic MILCON cost estimate in each SAR submitted to Congress. According to AFI 32-1021 (USAF, 2016), MILCON project development and cost estimation begins with base civil engineer units using a DD Form 1391, Military Construction Project Data, to explain and to justify the project through all levels of the Air Force, Office of the Secretary of Defense, Office of Management and Budget, and Congress. Each of these forms includes the cost estimate for a single project, which assists in the use of parametric estimating tools with historical cost data where applicable.

Congress has historically scrutinized the DoD for MILCON cost overruns of projects from the time of funding appropriation through project completion. The GAO has reviewed MILCON project processes along with specific in-depth case studies for projects of interest for some time. The first GAO study to focus on the cost estimating of MILCON projects was reported in 1981 and concerned the variability to actual costs. The latest GAO study on MILCON cost estimating was reported in 2018 and focused on the reliability of the estimates.

The first GAO (1981) fieldwork study analyzed a broad sample of 83 MILCON projects from Fiscal Years (FY) 1978–1980; these projects represented a variety of facility types in various stages of cost overruns, cost underruns, and close to budget amounts. They found that most projects were estimated at least 18

months prior to project bidding for contract and that it was not unusual for the contract amount to differ from the estimated amount that was submitted to Congress for budget. This is an important recognition considering the MILCON costs reported in SARs are inevitably estimated more than 18 months prior to contract bidding. Additionally, GAO found that even with the most accurate information at 100% complete design, the actual cost is still influenced by bidder interest in a particular project, fluctuations in labor and material costs, changes in requirements or design after budget submission, and changes in site location for geographical and/or environmental reasons.

"Congress has historically scrutinized the DoD for MILCON cost overruns of projects from the time of funding appropriation through project completion.

Concerned with constrained fiscal resources and the military's ability to effectively plan, estimate, and execute MILCON projects, Congress recently directed the Comptroller General of the United States to review and to report on DoD's MILCON cost estimating procedures. This mandate resulted in the 2018 GAO study, which analyzed MILCON appropriations from FYs 2005–2016 totaling $66 billion for all DoD MILCON projects during those 12 years. By the end of FY 2016, DoD had obligated $60.9 billion (92%) and expended $55 billion (83%). Research specific to FYs 2010–2016 discovered that DoD achieved $4.2 billion in MILCON project savings of which $1.6 billion had been reprogrammed to fund emergency projects—projects that did not receive the full requested appropriation, or projects needing additional funding. Regarding cost overruns, GAO (2018) stated that some differences between initial estimates and final costs for MILCON projects can be attributed to factors outside of DoD's control, such as unforeseen environmental and site conditions.

In a broader perspective, the construction project literature review identified many possible factors or causes for project cost overruns (Federle & Pigneri, 1993; Flyvberg, Holm, & Buhl, 2002; GAO, 1981; Giegerich, 2002; Harbuck, 2004; Jahren & Ashe, 1990; Thal, Cook, & White, 2010; Trost & Oberlender, 2003; Zentner, 1996). These articles span from 1981 to 2010 and cover a plethora of industry projects such as MILCON, transportation infrastructure and highways, nuclear construction, and naval facilities. Table 1 outlines a list of factors that were commonly identified in these articles as variables that can affect construction cost overruns.

TABLE 1. FACTORS AFFECTING CONSTRUCTION PROJECT COST OVERRUNS

	GAO, 1981	Jahren & Ashe, 1990	Federle & Pigneri, 1993	Zentner, 1996	Flyvberg, Holm, & Buhl, 2002	Giegerich, 2002	Trost & Oberlender, 2003	Harbuck, 2004	Thal, Cook, & White, 2010
Unforeseen Changes									
Changes in Scope/Requirements or Change Orders	✓	✓		✓		✓		✓	
Changes in Schedule or Delays						✓		✓	
Changes in Anticipated Bid Opening Date	✓								
Changes in Site Location	✓								
Bidding Environment and Contractor Behavior									
Contract Bidder Interest in Project or Number of Bids	✓	✓	✓				✓	✓	✓
Ratio/Difference: Low Bid to Government/Engineer Estimate		✓	✓						✓
Contractor History or Unsatisfactory Performance			✓			✓			
Disputes or Claims		✓				✓			
Bid Range: Highest to Lowest Bid			✓						
Design Process									
Changes, Errors, or Ambiguity in Design	✓							✓	
Design Effort or Funds Available for Design			✓	✓		✓			✓
Design Complexity						✓			
Design Length									✓
External Factors									
Fluctuations in Labor/Material Costs or Economics	✓						✓		
Local Government/Permitting Agencies or Politics					✓			✓	
Project Features									
Construction Type		✓	✓		✓				✓
Location or Site Requirements			✓		✓		✓		
Size		✓							
Construction Duration/Length			✓						
Estimation Process									
Cost Information Available							✓		
Estimator Team Experience							✓		
Estimate Effort or Time Allowed to Prepare Estimate							✓		
Leadership									
Improper Scope Definition				✓					
Lack of Estimate Accountability				✓					
Strategic Misrepresentation					✓				
Supervision Effort/Management Involvement			✓	✓		✓	✓		

Note. Those highlighted in green reflect three or more references indicating a similar factor in affecting cost overruns.

Even though MILCON cost estimates might represent a fraction of the total estimate associated with the actual acquisition of an MDAP, MILCON estimation still represents a vital process to investigate. Given the authors could find no published analysis concerning MILCON cost growth at a programmatic level, this study takes an empirical approach to determine whether cost growth or underruns statistically exist with respect to estimates. Specifically, this study addresses three questions:

1. What is the typical growth in program-level MILCON cost estimates for MDAPs led by the USAF?

2. Which variables or factors are statistically associated with program-level MILCON cost growth?

3. What, if any, is the association between SAR reported program-level estimates and actual project-level costs as of the current date of data?

Databases and Methods

To address these questions, two databases were created. The first captures program MILCON cost estimates from the SARs (with the implicit assumption that correct information is being recorded therein). The majority of this MILCON data initially originated from an internal Air Force Life

Cycle Management Center (AFLCMC) database of all SARs from 1966–2015. This is because the Defense Acquisition Management Information Retrieval (DAMIR) system (the current authoritative source for SARs) only contains automated SAR records from December 1997 to the present. The AFLCMC database derives from the original SAR sources dating back to 1966 (pre-DAMIR).

The AFLCMC database has 120 Air Force-led acquisition programs with 1,330 total SAR records. This study narrowed the 120 programs to 41 that contained at least one MILCON cost estimate. Seven of these acquisition programs were cancelled according to the AFLCMC database. This left the study with 34 programs to analyze. Because the internal AFLCMC database was last updated in December 2015, this study updated the SAR information for these 34 programs, resulting in 13 additional SARs. Lastly, two programs were excluded from analysis since the reporting duration from the first to last SAR was less than 12 months.

Therefore, the first database has 32 Air Force-led programs (as indicated in the SARs) with 444 associated SARs. Table 2 summarizes the data inclusions and exclusions taken to arrive at these 32 programs, while Table 3 displays these final 32 programs, commodity types, and total years of SAR reporting for each program. Of these programs, the mean and median SAR reporting times are 13 and 10.5 years, respectively. The dominant commodity type is aircraft, with 18 of the 32 programs (approximately 56%). All MILCON cost estimates and total program cost estimates were normalized from program base years to constant year 2018 using the appropriate inflation factors from the Secretary of the Air Force/Financial Management Cost and Economics (SAF/FMCE, 2018), Directorate of Economics and Business Management.

TABLE 2. PROGRAM MILCON DATABASE INCLUSIONS/EXCLUSIONS

Criteria	Δ Programs	Δ Reports	Total Programs	Total Reports	Years Included
Initial SAR data provided by AFLCMC	+ 120	+ 1,330	120	1,330	1966-2015
MILCON not reported in any SAR for the program	- 79	- 836	41	494	1966-2015
Acquisition program cancelled	- 7	- 59	34	435	1966-2015
Latest SARs added from DAMIR		+ 13	34	448	1966-2017
First to last SAR spans less than 12 months	- 2	- 4	32	444	1966-2017

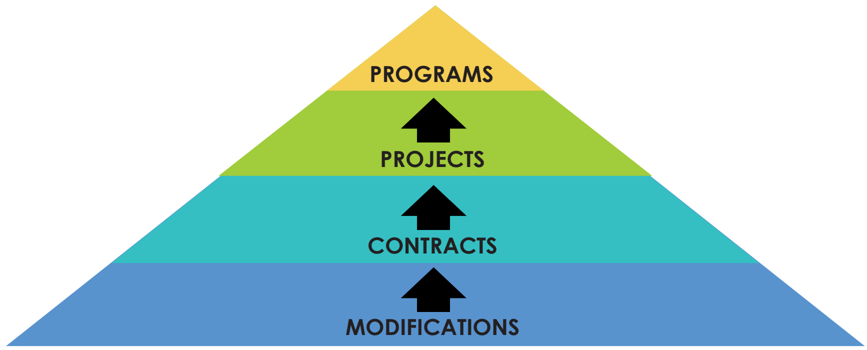
TABLE 3. 32 PROGRAMS INCLUDED IN PROGRAM MILCON DATABASE

	Weapon System Type	Total Years Reported
Short-Range Attack Missile (AGM-69A)	Missile	9
Minuteman III (LGM30G) Intercontinental Ballistic Missile	Launch Vehicle	11
A-7D Corsair II Carrier-Capable Subsonic Light Attack Aircraft	Aircraft	7
F-111 A/D/E/F Tactical Fighter Bomber	Aircraft	7
E-4 (Advanced Airborne Command Post; National Emergency Airborne Command Post)	Aircraft	10
AGM-86B (Air-Launched Cruise Missile)	Missile	9
Ground Launched Cruise Missile (BGM-109G)	Missile	12
KC-10A Aerial Refueling Tanker Aircraft	Aircraft	9
Global Positioning System Satellite Block I/II/IIA	Satellite	14
C-5B Military Transport Aircraft	Aircraft	7
Defense Meteorological Satellite Program (DMSP)	Satellite	16
Defense Support Program (DSP)	Satellite	14
Inertial Upper Stage (IUS)	Launch Vehicle	11
Advanced Cruise Missile (AGM-129A)	Missile	9
Peacekeeper (LGM-118A) Four-Stage Intercontinental Ballistic Missile	Launch Vehicle	9
C-17 Military Transport Aircraft	Aircraft	26
E-8A Joint Surveillance and Target Attack Radar System (JSTARS)	Aircraft	19
Titan IV (Complementary Expendable Launch Vehicle)	Launch Vehicle	17
F-22 All-Weather Stealth Tactical Fighter Aircraft	Aircraft	25
B-2A Spirit Heavy Strategic Bomber	Aircraft	10
Military Strategic and Tactical Relay (MILSTAR) Terminals	Electronic	8
National Airspace System (NAS)	Electronic	23
T-6A/B Joint Primary Aircraft Training System (JPATS)	Aircraft	21
C-130J Military Transport Aircraft	Aircraft	22
Space-Based Infrared System (SBIRS)	Satellite	22
C-5 Reliability Enhancement and Re-engining Program (RERP)	Aircraft	16
Global Hawk (RQ4)	Aircraft	14
C-27J Joint Cargo Aircraft (JCA)	Aircraft	10
Reaper (MQ9) Unmanned Aerial Vehicle	Aircraft	9
HC/MC-130J Personnel Recovery Aircraft	Aircraft	8
KC-46A Military Aerial Refueling and Strategic Military Transport Aircraft	Aircraft	7
Combat Rescue Helicopter (HH60W)	Aircraft	4

The second database consists of MILCON data from projects using the Automated Civil Engineer System – Project Management (ACES-PM). Examples of MILCON projects may include mission training complexes, aircraft hangars, or information system complexes. ACES-PM provides data for every individual project associated with a selected acquisition program. Key data include project cost information including appropriation, obligation, and expenditure. Since ACES-PM was fielded in 2000, this leaves a limited scope for project comparison with programs, which is acknowledged as a study limitation.

From the original 32 programs within the first database, only 11 programs included SAR estimates after 2000, when ACES-PM was fielded. Of these 11 programs, one program had more than 85% of its projects still in the design or ready-to-advertise status, and was therefore excluded from actual cost analysis. The remaining had less than 40% of the projects still in design or ready-to-advertise status. The final count of programs analyzed at the project level was 10, with nine categorized as aircraft and one categorized as a satellite. The total number of projects for these programs consisted of 216. The aircraft commodities included cargo, fighter, helicopter, tanker, trainer, and unmanned aerial vehicle programs. MILCON project data were pulled from ACES-PM and were current as of October 2018. (Note: due to confidentiality requirements, the authors cannot name the specific 10 programs of the listed 32 in Table 3 for this second database.) The information obtained from ACES-PM included contract data, contract modification data, and project data. The contract modification data were amalgamated into contract data and then subsequently amalgamated into program data. Figure 1 graphically depicts this process. As with the program SARs, all monetary values were normalized to constant year 2018 using the SAF/FMCE inflation factors

FIGURE 1. PROJECT MILCON DATABASE ROLL-UP PROCESS



The analysis incorporated a mixture of descriptive and inferential statistics to address the three primary research questions. Various reporting intervals of SAR reports were compared to the final SAR's MILCON cost estimate to analyze growth in the form of amounts and percentages. These intervals were from the start of reporting, after a quarter of reports had been submitted (25th percentile), at the median point of submitted reports (50th percentile), and after three-quarters of reports had been submitted (75th percentile). Descriptive measures consisted of the mean, median, standard deviation, maximum, and minimum values for the various reporting intervals of SAR reports.

The program-level roll-up from the Project MILCON Database was integrated with the Program MILCON Database for the 10 available programs to tie the SAR report variables to the project variables and actual MILCON costs. Cost growth was analyzed at the various stages of SAR reporting similar to the process just described. The primary difference in this cost growth analysis is that all SAR reporting stages were compared to programmed amounts, obligation amounts for projects with construction complete, and obligation amounts for projects with construction at least underway instead of the last SAR cost estimate reported.

Because both databases have relatively small sample sizes, continuous variables of percentile cost growth were converted into categorical binary variables, or dummy variables, to test for statistical dependency (via contingency table analysis). Three dummy variables were created for each measurement of cost growth to indicate (a) positive cost growth, or estimates increasing over time, (b) at least +/- 1% cost growth, or an increase or decrease of estimates over time by at least 1%, and (c) at least +/- 2% cost growth, or an increase or decrease of estimates over time by at least 2%. Table 4 lists these variables as well as other variables considered for analysis.

<table>
<tr><th colspan="3">TABLE 4. PROGRAM MILCON DATABASE VARIABLES</th></tr>
<tr><th>Cost Growth Variables for Descriptive Statistics</th><th>Dependent Cost Growth Variables for Contingency Tables</th><th>Independent Cost Growth Variables for Contingency Tables</th></tr>
<tr><td>Growth First to Last SAR ($ and %)</td><td>Growth First to Last SAR (positive %, >|1%| and >|2%|)</td><td>Commodity Type</td></tr>
<tr><td>Growth 1st/2nd/3rd Quartile Report to Last SAR ($ and %)</td><td>Growth 1st/2nd/3rd Quartile Report to Last SAR (positive %, >|1%| and >|2%|)</td><td>Prototype</td></tr>
<tr><td>Growth Mean to Last SAR ($ and %)</td><td>Growth Mean to Last SAR (positive %, >|1%| and >|2%|)</td><td>Modification</td></tr>
<tr><td>Growth Median to Last SAR ($ and %)</td><td>Growth Median to Last SAR (positive %, >|1%| and >|2%|)</td><td>Base Year</td></tr>
<tr><td>Growth Minimum to Last SAR ($ and %)</td><td></td><td>Mean MILCON Cost to Program Cost Ratio</td></tr>
<tr><td>Growth Maximum to Last SAR ($ and %)</td><td></td><td>MILCON Cost Estimate on Last SAR</td></tr>
<tr><td></td><td></td><td>Total Program Estimate on Last SAR</td></tr>
</table>

Although categorical variables can be tested for dependency through contingency tables, a relatively large sample is required for a Pearson's Chi-Squared test and the associated odds ratio. For small samples, Fisher's Exact Test is more appropriate and presents a conditional exact inference. An exact inference does not rely on assumptions that parameters hold true through infinity, but it is an exact calculation of a p-value given the data presented (Agresti, 1992). Because both of our databases had relatively small sample sizes, Fisher's Exact Test was used to test for variable dependency significance. The reader is directed to McDonald (2014, pp. 77–85) for more details regarding the use of Fisher's Exact Test. The next section highlights the results of the descriptive and inferential analysis of cost growth for MILCON MDAP programs.

Results

The first set of results ascertain the typical growth in program-level MILCON cost estimates for USAF-led MDAPs. Figure 2 displays cost growth as a percentage of total acquisition program costs from the first SAR cost estimate to the last SAR cost estimate for the 32 programs. The majority of programs (78%) show cost growth or cost savings within a 2% difference from the original estimate or a 0% cost growth, indicating minor program MILCON estimate changes over time. Table 5 displays mean and median cost growth in dollar value and percentage from the first SAR estimate, median SAR estimate, mean SAR estimate value, and median SAR estimate value to the last SAR estimate. Dissimilarities between means and medians reflect outliers (both positively and negatively) present throughout the phases of SAR reporting and when observing the dollar value or percentage. Notably, the percentage of cost growth shows less skewing and is used to analyze typical cost growth from cost estimates.

FIGURE 2. MILCON COST GROWTH AS PERCENTAGE OF TOTAL PROGRAM COST FROM FIRST TO LAST SAR COST ESTIMATES

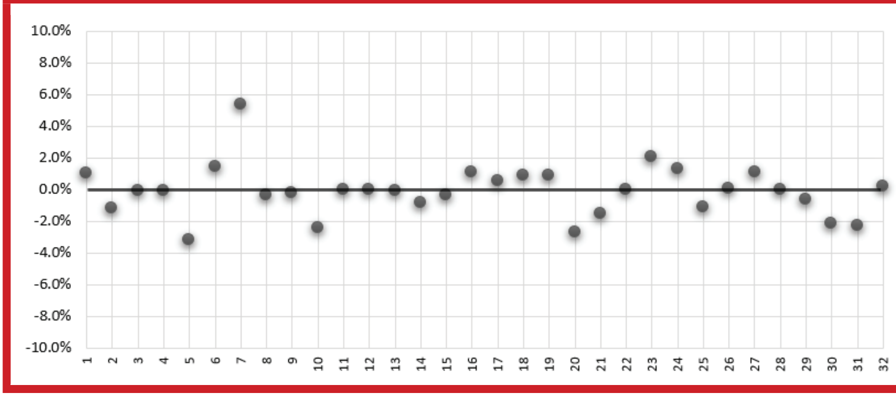


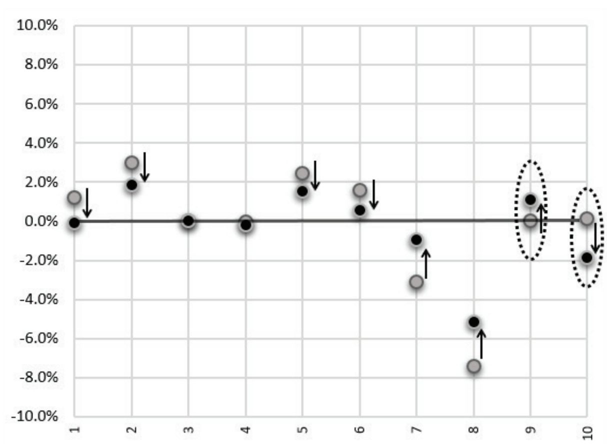
TABLE 5. DESCRIPTIVE STATISTICS OF MILCON COST GROWTH TO LAST SAR ESTIMATE (32 PROGRAMS)

	Mean ($M)	Median ($M)	Mean (%)	Median (%)
First Report to Last SAR Estimate	-$28.499	-$0.129	-0.11%	-0.03%
Median Report to Last SAR Estimate	$8.242	$0.000	-0.16%	0.00%
Mean Value to Last SAR Estimate	-$6.182	-$0.431	-0.14%	-0.04%
Median Value to Last SAR Estimate	$7.625	$0.000	-0.06%	0.00%

Utilizing a sample of 32 programs and comparing estimates to the final SAR's MILCON cost estimate yields a typical cost growth of MILCON estimates reported for USAF MDAPs on SARs, which is relatively small in comparison to the total program cost. Table 5's mean and median percentages indicate that cost growth percentages range from -0.16% to 0.00% of the total acquisition program cost reported on the last SAR. Due to the mean and median percentages leaning toward negative values, the central tendency for MILCON cost growth among MDAPs appears to be cost savings.

With respect to actual MILCON costs as reported by ACES-PM, Figure 3 highlights cost growth as a percentage to total acquisition program cost for the 10 programs in the second database. Each of the programs has two data points, which represent (a) the cost growth from the first reported SAR (gray), and (b) the cost growth from last reported SAR (black). It was anticipated that the cost growth percentages would move inward to the 0% cost growth target line from the first SAR to the last SAR as true (not estimated) MILCON costs were recorded and SAR cost estimates were updated to reflect these. This was not the case for two of these programs.

FIGURE 3. COMPARISON OF MILCON COST GROWTH FROM FIRST (GRAY CIRCLES) AND LAST (BLACK CIRCLES) SAR ESTIMATES TO ACTUAL MILCON COSTS



Note. Circled areas highlight where last estimates exceeded first estimates.

Table 6 outlines the same descriptive statistics as Table 5 with the exception of measuring cost growth against programmed and obligated amounts derived from accumulated actual projects instead of measuring cost growth against the last reported SAR estimate. The eighth listed program on the x-axis of Figure 3 has a significantly lower programmed and obligated amount than on the reported SAR estimates, which is skewing Table 5's means towards cost savings. This could be caused by unprogrammed projects that are still needed for the future or an improperly high estimate when reporting MILCON estimates in the SARs. Due to the small sample size of 10, this program was not removed for analysis. For the purpose of measuring central tendency values, the median may depict a better measurement for this dataset.

TABLE 6. DESCRIPTIVE STATISTICS OF MILCON COST GROWTH TO ACTUAL COSTS

	Mean ($M)	Median ($M)	Mean (%)	Median (%)
First Report to Programmed Amount	-$122.420	$30.394	0.43%	1.05%
Last Report to Programmed Amount	-$71.179	$31.662	0.33%	0.48%
Mean Value to Programmed Amount	-$74.819	$22.915	0.28%	0.51%
First Report to Obligated Amount (Construction Complete)	-$231.938	$3.756	- 0.37%	0.10%
Last Report to Obligated Amount (Construction Complete)	-$164.903	$20.346	- 0.47%	- 0.15%
Mean Report to Obligated Amount (Construction Complete)	-$184.337	-$5.084	- 0.51%	- 0.07%
First Report to Obligated Amount (Construction Underway)	-$198.090	$3.756	- 0.21%	0.10%
Last Report to Obligated Amount (Construction Underway)	-$146.850	-$2.774	- 0.32%	- 0.03%
Mean Report to Obligated Amount (Construction Underway)	-$150.489	-$2.017	- 0.36%	- 0.02%

Utilizing programmed amounts as a measurement of actual costs as of October 22, 2018, the median cost growth percentage from SAR reports ranges from 0.48% to 1.05% of the last reported total acquisition cost on a SAR. In dollar values, the median cost growth from SAR reports to programmed actual costs ranges from $22.92 million to $31.66 million. While the percentage of total acquisition program cost is relatively small, the dollar values appear significant when considering multiple acquisition programs that may encounter these cost growths from the reported MILCON estimate on SARs.

Both obligation amount measurements of actual costs display median central tendencies of less cost growth and even depicting cost savings. The median cost growth percentage from SAR reports ranges from -0.15% to 0.10% of the last reported total acquisition cost on the MDAP SAR. The median dollar amount of cost growth ranges from -$5.08 million to $20.35 million. These values may be smaller than the programmed amount measurement because the obligation amount does not include projects that have not begun construction yet, nor incorporate total costs for projects with construction still underway or not completely financially closed out.

Shifting to the inferential part of the analysis, those results are now presented that address the second question: which variables or factors are statistically associated with program-level MILCON cost growth?

Drawing from both the Program MILCON Database and Project MILCON Database, dichotomous (dummy) variables were utilized in contingency table analysis to identify potential dependent variables, which showed significance in Fisher's Exact Test with a *p*-value less than 0.10. This analysis was performed using JMP Pro 13, predictive analytics software that elevates statistical discovery.

A significant right tail shows that the tested cost growth is more probable if the tested independent dummy variable is indicated with a "1" than if it is a "0." For example, a right tail for the *"≥ 15 Years of SAR Reports"* dummy variable tested against positive cost growth indicates that positive cost growth is more probable if the program has 15 or more years of SAR reports. A significant left tail shows that the opposite is more probable. Continuing with the first example, a significant left tail for the *"≥ 15 Years of SAR Reports"* dummy variable tested against positive cost growth indicates that positive cost growth is less probable if the program has 15 or more years of SAR reports. For the purpose of this study, all of the contingency table tests use one-tailed hypotheses to determine directionality of the variables' dependency.

"It can be expected that greater deviations of cost growths or savings in comparison to total acquisition costs would occur on larger MILCON estimates with smaller total acquisition costs.

Table 7 illustrates the results for the 32 programs, while Table 8 highlights the results using ACE-PM data for the subset of 10 programs. (Note: For brevity, these tables reflect the results of multiple 2 x 2 Fisher Exact tests.) Significance measurements of *p*-values are marked with asterisks (*). One asterisk indicates a significant Fisher's Exact *p*-value of 0.10 or less, two asterisks indicate a *p*-value of 0.05 or less, and three asterisks indicate the highest significance with a *p*-value of 0.01 or less. Additionally, the right- and left-tailed significance is marked to show whether the independent factor tested more probable (right tail) or the opposite tested more probable (left tail). Due to the exploratory nature of this study, spurious findings are possible. Therefore, those findings with a *p*-value level less than 0.01 or by the number of significant (*p*-value 0.10 or less) Fisher's Exact tests are the ones the analysis primarily addresses in significance.

TABLE 7. TOP SIGNIFICANT FACTORS FOR COST GROWTH TO LAST SAR (32 PROGRAMS)

Table Legend:
- * *p*-value < 0.10
- ** *p*-value < 0.05
- *** *p*-value < 0.01
- L left-tail significance
- R right-tail significance

	≥15 Years of Reports	Aircraft	Missile	<0.5% Avg MILCON % to Total	>5% Avg MILCON % to Total	<$10M MILCON on Last SAR	<$50M MILCON on Last SAR	>$10B Total Program on Last SAR
First to Last (Positive Growth)	R ***					L **		
First to Last (>|1%| Growth)				L **	R *	L *	L *	R *
First to Last (>|2%| Growth)		R *		L *				R *
Q1 to Last (Positive Growth)						L **		
Q1 to Last (>|1%| Growth)				L **	R **			
Q1 to Last (>|2%| Growth)								
Q2 to Last (Positive Growth)		R ***					L ***	R **
Q2 to Last (>|1%| Growth)			R *		R **			
Q2 to Last (>|2%| Growth)								
Q3 to Last (Positive Growth)	R **	R **						R *
Q3 to Last (>|1%| Growth)		L *	R **		R **			
Q3 to Last (>|2%| Growth)		L *	R **		R **			
MED to Last (Positive Growth)	R *	R **						
MED to Last (>|1%| Growth)								
MED to Last (>|2%| Growth)								
MEAN to Last (Positive Growth)	R *	R **					L *	
MEAN to Last (>|1%| Growth)								
MEAN to Last (>|2%| Growth)								
Total Significant Contingency Tables	4	7	3	3	5	3	3	4

TABLE 8. TOP SIGNIFICANT FACTORS FOR COST GROWTH TO PROGRAMMED AMOUNTS (10 PROGRAMS)

Table Legend:
- * *p*-value < 0.10
- ** *p*-value < 0.05
- *** *p*-value < 0.01
- L left-tail significance
- R right-tail significance

	<4 Bases with Projects	<$50M Programmed for Projects	>$400M Programmed for Projects	<10 Different Companies with Project Contracts	<10,000 Contracted Performance Period Days	>$10B Total Program on Last SAR	<$10M in Contract Modifications	<$3M in Contract Modifications	<200 Contract Modifications	<50 Contract Modifications	≥75% of Projects w/Contract Modifications
First to Programmed (Positive Growth)											
First to Programmed (>|1%| Growth)	L *	L ***								L ***	
First to Programmed (>|2%| Growth)		L *	R *	L **	L *					L *	
Q1 to Programmed (Positive Growth)											
Q1 to Programmed (>|1%| Growth)		L *	R *	L **	L *					L *	
Q1 to Programmed (>|2%| Growth)	L **		R **	L ***	L **						
Q2 to Programmed (Positive Growth)											
Q2 to Programmed (>|1%| Growth)		L *	R *	L **	L *					L *	
Q2 to Programmed (>|2%| Growth)	L *		R ***	L **	L ***	R **	L *	L **	L **		
Q3 to Programmed (Positive Growth)											R *
Q3 to Programmed (>|1%| Growth)			R *		L *						
Q3 to Programmed (>|2%| Growth)											
Last to Programmed (Positive Growth)											R *
Last to Programmed (>|1%| Growth)			R *		L *						
Last to Programmed (>|2%| Growth)											
MED to Programmed (Positive Growth)											R *
MED to Programmed (>|1%| Growth)		L *	R *	L **	L *					L *	
MED to Programmed (>|2%| Growth)	L *		R ***	L **	L ***	R **	L *	L **	L **		
MEAN to Programmed (Positive Growth)											
MEAN to Programmed (>|1%| Growth)				L *							
MEAN to Programmed (>|2%| Growth)	L *		R ***	L **	L ***	R **	L *	L **	L **		
Total Significant Contingency Tables	5	5	10	9	10	3	3	3	3	5	3

One predictor variable with a high frequency of significance among the various reporting intervals of SARs was cost growth for programs that had MILCON estimates averaging more than 5% of the total program costs. All five of the significant average MILCON % dummy variables with respect to +/- 1% and +/- 2% cost growth contained significant right tails. This means that cost deviation of more than 1% or 2% of the total acquisition cost is more probable for programs averaging MILCON estimates more than 5% of the total program cost. It can be expected that greater deviations of cost growths or savings in comparison to total acquisition costs would occur on larger MILCON estimates with smaller total acquisition costs.

The other predictor variable with the most counts of significant tests among varying reporting intervals of SARs was cost growth for the aircraft commodity. The four significant aircraft commodity tests (as shown in Table 7, under the aircraft column) with respect to positive cost growth contained significant right tails, which means that positive cost growth is more probable for aircraft programs than nonaircraft programs. This could be due to higher total acquisition costs of aircraft programs compared to nonaircraft programs. The average total acquisition cost for aircraft programs was $7.8 billion, whereas nonaircraft programs averaged $1.6 billion. In summary, positive cost growth in MILCON estimates is more likely for aircraft programs, but the growth is probably less than 1% of the total program cost.

Focusing on the project level (Table 8), the predictor variable, which was one of the most frequently significant among various reporting intervals of SARs tested against programmed amounts, was cost growth for programs with more than $400 million of MILCON funds programmed for projects. All 10 of these significant tests with respect to +/- 1% and +/- 2% cost growth contained significant right tails, which means cost deviation of more than 1% or 2% of the total acquisition program cost is more probable for programs that currently have more than $400 million cumulatively programmed for MILCON projects. Perhaps a larger dollar amount programmed for MILCON projects shows increases in planned projects' costs or shows that new projects were added to the mission requirement for the acquisition program, thereby deviating SAR estimates by more than 1% or 2% of the total program cost.

A similar significant predictor variable was cost growth for programs with fewer than 10,000 cumulative performance-period days contracted for projects. This variable is a summation value from all contracts for all projects within a program, consisting of a cumulative number of days on contract for performance periods. All 10 of these significant tests with respect to +/- 1% and +/- 2% cost growth contained significant left tails, which means cost deviation of more than 1% or 2% of the total acquisition cost is more probable for programs with 10,000 or more cumulative performance-period days on contracts for all projects within the program. This finding suggests that programs requiring more performance-period days cumulatively across all projects for the program are more likely to experience changes in costs up or down from the original SAR estimates.

Another most significant predictor variable was cost growth for programs having project contracts with fewer than 10 different companies. All nine of these significant tests against +/- 1% and +/- 2% cost growth contained significant left tails, which means cost deviation of more than 1% or 2% of the total acquisition cost is less probable for programs having project contracts with fewer than 10 different companies. This finding also suggests that programs working with 10 or more companies are more likely to experience increased costs from the original SAR estimates.

Discussion and Conclusions

The study turns now to answering the three questions posed earlier. The first question concerned the typical growth in program-level MILCON cost estimates for MDAPs led by the USAF. Analysis showed that growth deviations decreased over reporting time with the mean SAR estimate being $6.2 million greater than the MILCON cost estimate on the last report. Using the median, the typical SAR estimate was only $431 thousand greater than the MILCON estimate from the last report. This equates to a cost savings of 0.04% of the total program cost on the last SAR report.

Considering cost growth from the first to the last MILCON SAR estimate, the typical amount was -$28.5 million, with the median cost growth being -$129 thousand, thereby suggesting cost savings as the typical trend for MILCON in MDAPs led by the Air Force. Utilizing a percentage to total program costs, the mean cost growth from first to last SAR is -0.11% of the total program cost, and the median cost growth across a program's span of SARs is -0.03% of the total program cost.

The second question concerned which variables or factors are statistically associated with program-level MILCON cost growth. First, aircraft commodities tend to drive positive cost growth for MILCON projects but not by more than 1% of the total program cost. Second, a higher average percentage of MILCON cost estimates reported on SARs for a program compared to the total program cost estimate can drive cost growth or savings by more than 1% or 2% of the total program cost. Third, more funds cumulatively programmed for projects within a program may drive cost growth or savings by more than 1% or 2% of the total program cost. Fourth, higher cumulative performance-period days on contracts across all projects within a program may indicate cost growth or savings by more than 1% or 2% of the total program cost. Lastly, having more companies contracted for projects within a program (greater than 9 as seen in Table 8) may drive cost growth or savings by more than 1% or 2% of the total program cost.

Several other factors appeared significant and future studies should investigate them as possible drivers to MILCON cost growth in MDAPs. The number of bases authorized for projects within a program, the number of contract modifications, and the monetary value of contract modifications may affect the size of cost growth in comparison to total program costs. Additionally, the number of years between the first and last MILCON SAR estimate and the percentage of projects with contract modifications may drive positive cost growth.

The last question concerned the association, if any, between SAR-reported program-level estimates and actual project-level costs. The Project MILCON Database with 10 programs had considerably fewer sample programs than the first database of 32 programs, but it allowed analysis of actual cost growth from projects that have been completed or at the minimum have been authorized for programming as of October 22, 2018. With various MILCON requirements for different programs and commodities, dollar values varied greatly across programs. For the purpose of analyzing the association between cost estimates on the SARs and actual costs from projects, percentages of cost growth were used. Zero percent cost growth suggests perfect estimation with no disconnect between SAR reportings and actual costs.

Analyzing the median cost growth percentage from all reporting intervals of SARs to the current programmed amount, results range from 0.48% to 1.05% of the total program cost. This suggests that the SAR estimates were slightly underestimated to what has been programmed for projects within the acquisition program. The median cost growth percentages compared to the current obligation amounts range from -0.15% to 0.10% of the total program cost. This proposes that the SAR estimates are generally closer to what has been already obligated on projects and could remain more accurate if no other obligations were made toward the programmed amounts. This course of action is highly unlikely in the authors' opinion.

Previously mentioned references share commonalities with the findings of this study. Federle and Pigneri (1993) found that the duration of the construction project can affect cost overruns for the project. The study found that the cumulative days of contracted performance were significant regarding cost growth at the programmatic level of MILCON. Four studies from Table 1 showed that the type of project or construction affected the cost overrun of the project. This study found that MILCON projects for aircraft acquisition programs were more likely to experience cost growth than the nonaircraft MDAPs when testing at the programmatic level. Table 1 also showed five studies that found changes in requirements or the presence of change orders to be an indication of cost overruns in construction projects. This study found both the monetary value and the number of contract modifications tested relatively significant for MILCON in acquisition programs. For example, in Table 8, the analysis suggests that programs with fewer contract modifications or total amount of modifications have a greater chance of staying within 2% of the final programmed budgeted amount from about the halfway completion point and onward. Lastly, three studies reported that the number of project performance locations drives cost overruns. From Table 8, we see that the number of different locations required for the program tested significant as well.

With numerous published studies regarding MILCON project overruns and general construction overrun factors, MILCON cost growth for Air Force MDAPs had yet to be analyzed in a published forum. Although using only a small representative sample of acquisition programs, this study found typical MILCON cost growth to be negative, which indicates more cost savings than cost growth across SAR MILCON estimates. The savings are typically less than 0.2% of the total program cost, which implies minimal impact to MDAP decisions regarding the weapon system as a whole. However, this finding contradicts MILCON cost overruns as reported previously by the GAO.

The early MILCON estimates from SARs compared to current programmed or obligated values for projects suggests a slight disconnect in estimating in the SAR reports. Though estimates got more accurate from the first to the last SAR for most programs, Table 6 shows the last SAR's median MILCON cost estimate was approximately $31 million underestimated compared to projects currently authorized and appropriated for the programs. Though the median cost growth percentage from last SAR to programmed amount is only 0.48% of the total acquisition program's cost, the dollar value can add up and impact budgetary decisions about scarce resources.

The analyses presented in this article help the cost community identify the characteristics of MILCON projects that have historically deviated the most from the estimate. Consequently, the cost community can make better resource decisions in allocating time and effort in developing these estimates. For example, based on analysis findings, an aircraft-associated MILCON project with more than 10,000 anticipated cumulative performance-period days should have more cost-estimating resources allocated to it. Additionally, decision makers for these types of programs should require robust justification and evidence supporting these estimates.

In conclusion, the results, in addition to the differences between the mean and median values, suggest two macro statistical findings. One, the positive median values suggest that the typical project is experiencing cost overruns, which agrees with the GAO findings from 1981 to 2018. Two, in contrast to the first macro finding, the negative mean values suggest a few projects costing much less than expected. Therefore, when pooling all the projects together, the overall program is showing a cost savings when assessing SAR cost estimates over time. Going forward, future studies should build upon this study with further data from ACES-PM to ascertain whether the trend detected here continues.

References

Acquisition Category. (2018). In *AcqNotes* [Online encyclopedia]. Retrieved from http://acqnotes.com/acqnote/acquisitions/acquisition-category

Agresti, A. (1992). A survey of exact inference for contingency tables. *Statistical Science, 7*(1), 131–177.

Federle, M.O., & Pigneri, S.C. (1993). Predictive model of cost overruns. In *Transactions of AACE International: 1993* (pp. L 7.1–7.9). Morgantown, WV: AACE International.

Flyvberg, B., Holm, M. S., & Buhl, S. (2002). Underestimating costs in public works projects: Error or lie? *Journal of the American Planning Association, 68*(3), 279–295. Retrieved from https://www.tandfonline.com/doi/abs/10.1080/01944360208976273

Giegerich, D. B. (2002). Early warning signs of troubled projects. In *AACE International Transactions: 2002* (pp. CDR 2.1–2.8). Morgantown, WV: AACE International.

Government Accountability Office. (1981). *Why actual costs of military construction projects vary from their estimates* (LCD-81-17). Retrieved from https://www.gao.gov/products/LCD-81-17

Government Accountability Office. (2018). *Action needed to increase the reliability of construction cost estimates* (GAO-18-101). Retrieved from https://www.gao.gov/products/GAO-18-101

Harbuck, R. H. (2004). Competitive bidding for highway construction projects. In *AACE International Transactions: 2004* (pp. EST 9.1–9.4). Morgantown, WV: AACE International.

Jahren, C. T., & Ashe, A. M. (1990). Predictors of cost-overrun rates. *Journal of Construction Engineering and Management, 116*(3), 548–552.

Major Defense Acquisition Program, 10 U.S.C. § 2430. (2017). Retrieved from https://www.law.cornell.edu/uscode/text/10/2430

McDonald, J. H. (2014). *Handbook of biological statistics* (3rd ed.). Baltimore, MD: Sparky House Publishing.

Secretary of the Air Force/Financial Management Cost and Economics. (2018). Fiscal year 2018 inflation tables. In *AF Portal* [Online portal].Retrieved from https://www.my.af.mil/gcss-af/USAF/ep/contentView.do?contentType=EDITORIAL&contentId=c6925EC1756020FB5E044080020E329A9&channelPageId=s6925EC1350790FB5E044080020E329A9&programId=t6925EC2D91620FB5E044080020E329A9

Selected Acquisition Reports, 10 U.S.C. § 2432. (2010). Retrieved from https://www.gpo.gov/fdsys/granule/USCODE-2010-title10/USCODE-2010-title10-subtitleA-partIV-chap144-sec2432

Selected Acquisition Report. (2018). In *AcqNotes* [Online encyclopedia]. Retrieved from http://acqnotes.com/acqnote/acquisitions/selected-acquisition-report-sar

Thal, A. E, Cook, J. J., & White, E. D. (2010). Estimation of cost contingency for Air Force construction projects. *Journal of Construction Engineering and Management, 136*(11), 1181–1188.

Trost, S. M., & Oberlender, G. D. (2003). Predicting accuracy of early cost estimates using factor analysis and multivariate regression. *Journal of Construction Engineering and Management, 129*(2), 198–204.

U.S. Air Force. (2016). *Planning and programming military construction (MILCON) projects* (AFI 32-1021). Washington, DC: Author.

Zentner, R. S. (1996). Accurate estimates start with clear pictures. In *Transactions of AACE International: 1996* (C&S/M&C 10.1–10.6). Morgantown, WV: AACE International.

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