Guidance Unit Cost (GUC) Models for MILCON Programming Estimates

Author: Thomas A. Adams, P.E., C.C.E
Air Force Civil Engineer Center,
Operations Directorate
HQ AFCEC/COSC
Tyndall AFB, FL 32403-5319

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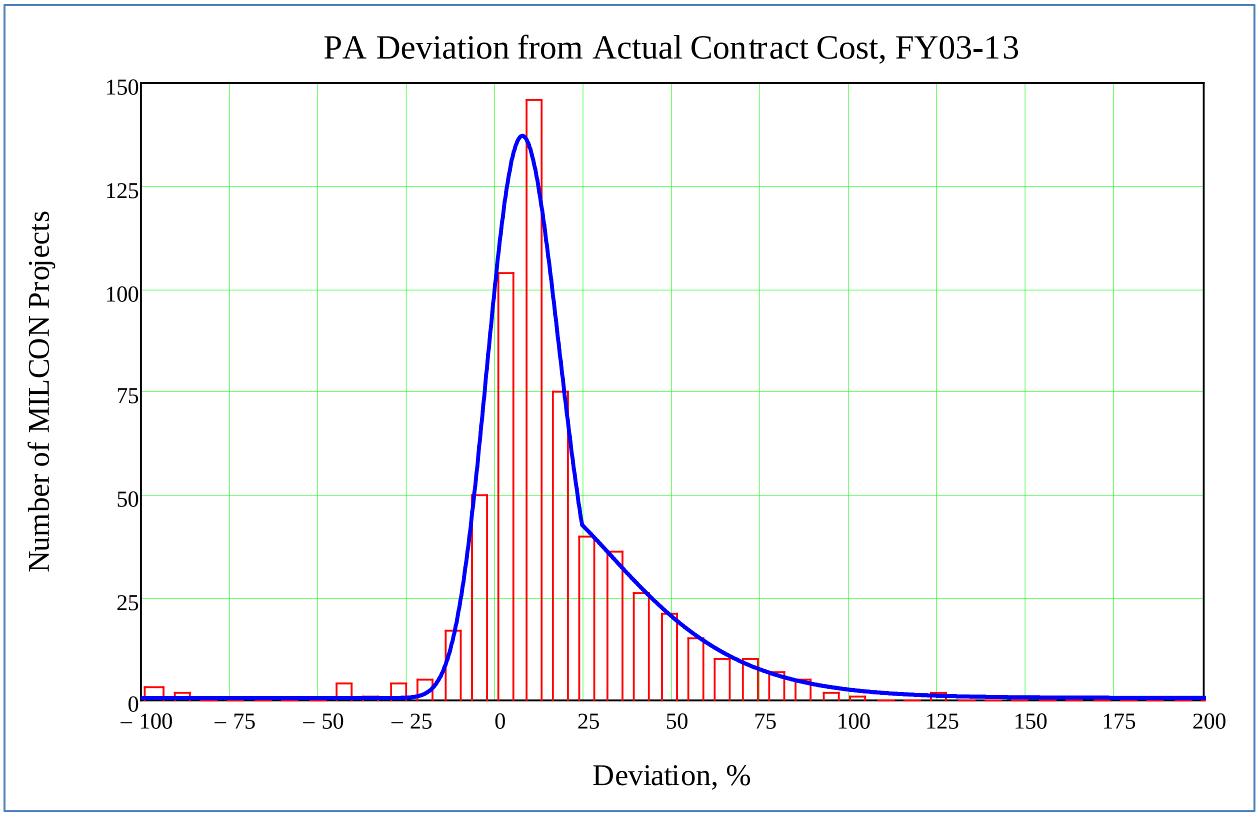
PURPOSE: To improve the accuracy of USAF MILCON programming estimates.

BACKGROUND

Estimate Accuracy

Accurate MILCON programming estimates are necessary so that Congress may allocate funds for an approved project[1]. Overestimate the requirement, and funds are lost for other mission needs. Underestimate the requirement, and the approved project may be delayed until either additional funds are procured, or the project is cancelled. As Figure 1 shows, AF MILCON[2] programming estimates are marginally acceptable. Consider that the target accuracy is 100 - 125% of actual cost (0 - 25% error). Seven percent (7%) of the project estimates fell below actual cost; 36% of estimates were greater than 125% of actual cost. Only 57% of FY03-13 AF MILCON programming estimates fell within the desired accuracy range.[3]

Figure 1: PA Deviation from Actual Contract Cost, FY03-13

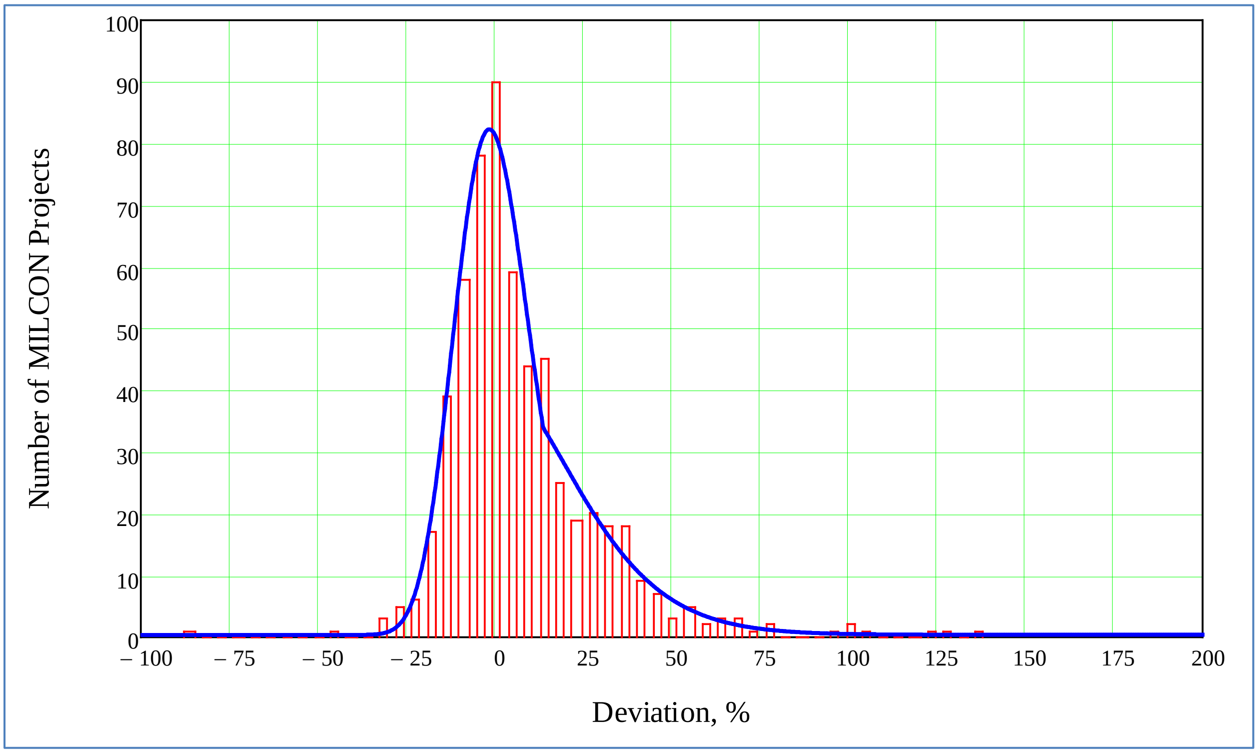


After a project is approved, funds allocated, and project requirements established, the project is designed either by an independent A&E firm (in a design-bid-build, or DBB contract) or the construction contractor (in a design-build, or DB contract). An independent government cost estimate (IGE) is then generated by the project engineer and is provided to the Contracting Officer for use in negotiations. The target accuracy for the IGE is ±10% of actual cost.

[1] Congressionally allocated funds are identified as the "programmed amount" or PA
[2] Database of 588 FY03-13 CONUS, New Construction MILCON projects
[3] Data obtained from the Historical Analysis Generator II (HII) database

We expect the IGE to be more accurate than the programmed amount (PA) and this is confirmed by the data. Figure 2 compares the IGE with the actual contracted project cost and shows that the expected IGE estimate is 108% of actual cost. But while the IGE distribution is tighter than the PA distribution (implying greater accuracy), the distribution is still skewed and has a relatively large standard deviation. Only 51% of IGE estimates fall within ±10% of actual cost.

Figure 2: IGE Deviation from Actual Contract Cost, FY03-13

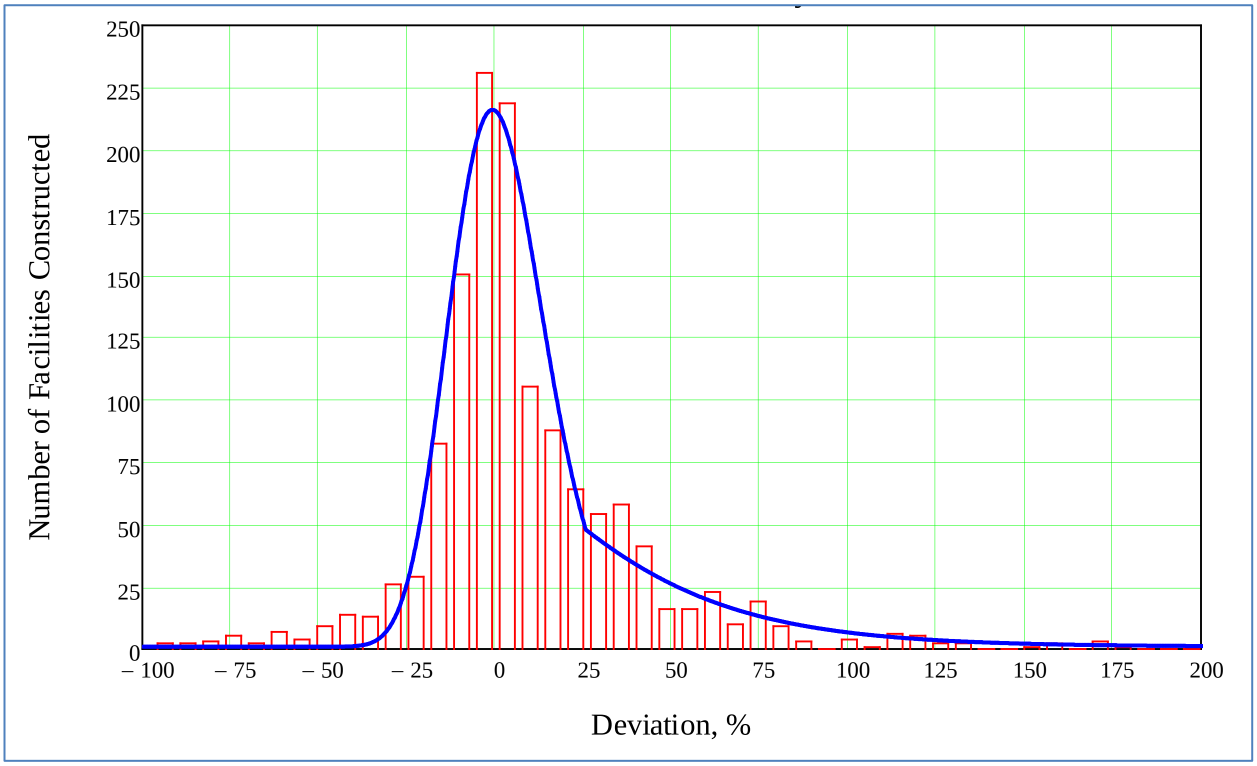


The basic components of the IGE are the project support costs[4] and the Facility Gov't Estimates (FGE). The FGE is the estimated cost of a primary facility in the construction project. This is the functioning facility minus site-specific requirements such as demolition, site work, pavements, etc. Since a typical MILCON project involves construction of multiple facilities[5], an IGE can be comprised of multiple FGEs (along with associated support costs). The FGE(s), the IGE, and the PA are collected and stored in the Historical Analysis Generator II (HII) database. The project engineer (usually an engineer from USACE) also enters the actual facility costs from the construction company into the HII database.

Figure 3 compares the FGE against actual facility costs. We find that the FGE, on average, overestimates actual costs by 12%. Less than half (45%) of the FGEs are within ±10% of actual costs. These statistics suggest that the FGE is the primary source of IGE error. The historical evidence (statistics) suggests that there is ample room for improvement.

[4] design fees + costs for construction outside the facility 5-foot perimeter … pavements / utilities / landscaping, etc.
[5] 1,342 facilities were built in 588 CONUS, New Construction MILCON projects program years FY03-13

Figure 3: FGE Deviation from Actual Facility Cost, FY03-13



Basis of the Programming Estimate

According to UFC 3-730-01, Programming Cost Estimates for Military Construction, two methods are available for calculating programming estimates. The first method is called "parametric estimating." Parametric estimating is a computer-based procedure that uses facility component models to build the estimate. The second method is the "guidance unit cost" (GUC) method outlined in UFC 3-730-01, Programming Cost Estimates for Military Construction. This method uses the calculated unit costs (per square foot) of new construction for the most common types of military facilities (such as Aircraft Hangars, Child Care Centers, HQ Buildings, Warehouses, etc.).

Parametric Estimates

Parametric estimating uses information from historical cost databases, current construction practices, and facility engineering & construction technology. For instance, to estimate the cost of a 6-inch steel reinforced concrete floor and foundation to a Supply Warehouse, the cost estimator may input the perimeter, the floor area, and the degree of reinforcement into a "floor and foundation" component model. This model would provide the expected cost based on the inputs and historical data. A common parametric cost estimating tool in the AF is PACES (**PA**rametric **C**ost **E**ngineering **S**ystem)[6].

If the programmer has access to accurate & detailed project definition and scope, the parametric estimate can be quite accurate. Conversely, parametric techniques cannot compensate for poor project definition and scope. In such cases, another estimating procedure should be used.

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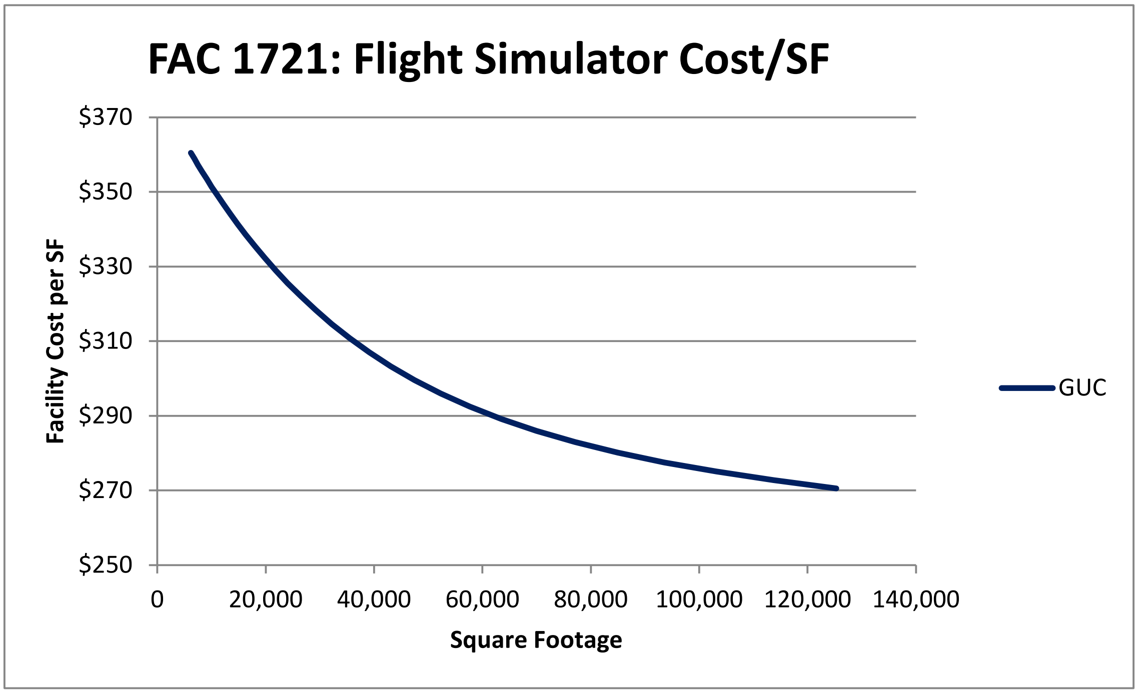
[6] Developed by AECOM

GUC Estimates

Published in UFC 3-701-01, DoD Pricing Guide, facility GUCs are updated annually (if an adequate sample size is available)[7] to reflect the very latest average DoD unit price paid. GUC costs are normalized for square footage, location, cost escalation, and technological advancement. The programmer then readjusts the programming estimate to the actual conditions using the appropriate adjustment data referenced in UFC 3-730-01, Section 4.

Figure 4: GUC Example Adjusted for SF



Sometimes, a programming estimate is required even though the project has poor definition and scope. Parametric estimating techniques cannot compensate for these defects and should not be used. In such cases, GUC estimating procedures should be used. Considering that few MILCON projects begin with an accurate & detailed project definition and scope, this report shall focus on improving GUC estimating methods.

Budgetary Impacts to GUC Methodology

The DoD budget is shrinking due to the nation's severe debt crisis. Budget cuts are expected to further shrink each Service's MILCON budget. In fact, the Air Force MILCON budget declined an average of 50% per year for the past three years – from $3.3B in FY10 to $0.4B in FY13. The number of projects decreased at a similar rate – from 229 in FY10 to 30 in FY13. As such, the number of MILCON projects from which to develop GUC values will be marginal at best. GUC values cannot be published for OSD facility analysis category (FAC) codes with insufficient project data.

Heterogeneity Issues in GUC Methodology

OSD FAC codes attempt to consolidate similar, homogeneous facilities into a single reference code. In this way, we are able to increase the amount of data points to develop annual GUC

[7] Currently, GUC rules mandate at least three projects per OSD facility analysis category (FAC) code across the last three FYs (or four projects across the last four FYs if the previous condition is not met) to update GUC values. If these conditions are not met, the GUC for that facility type is not updated.

updates. If individual Service's category codes (CatCodes) were used, the sample size would be much smaller and probably not meet the minimum requirements to publish GUC values in UFC 3-701-01. However, consolidating AF CatCodes under an OSD FAC codes do not always meet the requirements of homogeneity. For example, FAC 1711, General Purpose Instruction Building, attempts to consolidate the following AF category codes:

1. 171152, ACADEMIC LECTURE HALL
2. 171211, FLIGHT TRAINING CLASSROOM
3. 171213, FLIGHT TRAINING, UPT/UNT
4. 171447, RESERVE FORCES COMMUNICATIONS & ELECTRONIC TRAINING
5. 171449, RESERVE FORCES AEROMEDICAL EVACUATION TRAINING
6. 171618, FIELD TRAINING FACILITY
7. 171620, RUNWAY CONTROL STRUCTURE
8. 171621, TECHNICAL TRAINING CLASSROOM
9. 171627, AETC TECHNICAL TRAINING SUPPORT
10. 171628, LAUNCH OPERATIONS TRAINING FACILITY
11. 171712, TARGET INTELLIGENCE TRAINING
12. 171813, SAFETY EDUCATION FACILITY
13. 171815, NCO PROFESSIONAL MILITARY EDUCATION CENTER
14. 171833, BASIC MILITARY TRAINING
15. 171844, OFFICER TRAINING
16. 171851, AIR UNIVERSITY PROFESSIONAL/TECHNICAL EDUCATION
17. 171853, US AIR FORCE ACADEMY ACADEMIC TRAINING
18. 171875, MUNITIONS LOAD CREW TRAINING

One might wonder what a Runway Control Structure (item #7 above) has in common with an Academic Lecture Hall. Of course, the AF category code description does NOT indicate that CatCode 171620 is a type of instruction facility.

But even among facilities with seemingly similar CatCodes, statistical evidence will sometimes reject the assumption of homogeneity. For instance, the AF built 28 facilities in FAC 1711 in FY03-13. CatCodes 171152, 171211, 171449, 171621, 171627, 171815, 171851, and 171875 were represented. A statistical analysis of variance (ANOVA) test was run to check the homogeneity assumption. The test showed that CatCode 171211, Flight Training Classroom was significantly different than the remaining sample of FAC 1711 facilities. GUC methodology breaks down and loses accuracy when it uses heterogeneous samples.

IMPROVING GUC ESTIMATES

To compensate for GUC method deficiencies, OSD commissioned a study in June 2011 to refine the existing methods of calculating GUC indices.[8] Four of the six recommendations are significant[9] and can be validated using statistical analysis. However, no recommendation was made regarding how to compensate for the diminishing project sample sizes due to the substantial reduction in the MILCON Program.

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[8] Refinements in Deriving Guidance Unit Cost (GUC) for Military Construction, by: L-3 Stratis, 16 Nov 2011

[9] 1.) more accurate data entry, 2.) granular breakout of analogous projects, 3.) use facility-unique size adjustment curves, 4.) normalize for design differences

The project sample size issue was discussed at a Tri-Services Cost Engineering Meeting (Army, Navy, AF, and Defense Health Agency cost engineering experts) held in Atlanta, June 2013. A modeling alternative to the existing GUC method was proposed and discussed. Using a GUC model, built on data spanning 10+ yrs rather than using the existing GUC method (using at least 3 data points no more than 3-yrs old[7]) reduces the requirement for recent MILCON project data.

Modeling has several distinct advantages over the existing GUC methodology (i.e., calculating a small-sample average). First, a model can use "time" as a variable and thereby mix old with new data to increase the sample size. The age of the data is no longer a limiting factor.

Second, the increased sample size generates conditions for accurately estimating cost distribution variance. This model variance can be used to create confidence intervals and provide our programmers with an objective measure of how well their estimate compares with similar, historical projects.

A third modeling advantage is the ability to use single-factor ANOVA to test various COST assumptions. For instance, single-factor ANOVA can filter out heterogeneous CatCodes from the model; can be used to estimate area cost factors (ACFs) and escalation curves; and can test the significance of other process variables (number of bids, small business / 8A contract impacts, construction method, sustainability rating, etc.) on facility cost.

Model Type

To begin the modeling process, we first need to determine the function type that best fits the data. Figure 4 would be a good place to start since it is a model recognized and indorsed by the senior cost engineering experts in DoD. Extrapolating to the left, we note that the function gets very large as the facility square footage (variable *x*) approaches zero. Extrapolating to the right, we note that the slope of the function increases slowly toward zero. Alternatively, we may say that the function appears to converge to a constant. Mathematically, we may write:

Condition 1: $\lim_{x\to 0} \frac{f_b(x)}{x} = \infty$

Condition 2: $\lim_{x\to \infty} \frac{f_b(x)}{x} = C$

If $f_b(x) \equiv a \cdot x + b$, (where "$a$" is a constant) both conditions above are met. However, our cost function, $f_b(x)$, now tells us that if we choose not to build a facility (i.e., $x = 0$), then we still have a cost … $f_b(x) = a \cdot 0 + b = b$. From this condition, we see that ***b*** cannot be a constant but rather must be a function of ***x***. So $f_b(x) \equiv a \cdot x + b(x)$ and

Condition 3: $\lim\limits_{x\to 0^+} b(0^+) = 0$

Revisiting conditions 1 & 2, we find that the following sub-conditions must hold true in addition to condition 3:

Condition 1a: $\lim_{x\to 0^+} \frac{b(x)}{x} = \infty$

Condition 2a: $\lim_{x\to \infty} \frac{b(x)}{x} = 0$

One function that fits the above requirements (but there could be others) is $b(x) = -c \cdot \sqrt{x} \cdot \ln x$ where ***c*** is a constant. We see that condition 1 is met:

$$\lim_{x\to 0^+} \frac{b(x)}{x} = \lim_{x\to 0^+} \frac{-c \cdot \sqrt{x} \cdot \ln x}{x} = \lim_{x\to 0^+} \frac{-c}{\sqrt{x}} \cdot \ln x = \frac{-c}{0} \cdot \ln 0^+ = (-\infty) \cdot (-\infty) = \infty$$

Condition 2 is also met:

$$\lim_{x\to\infty}\frac{b(x)}{x}=\lim_{x\to\infty}\frac{-c\cdot\sqrt{x}\cdot\ln x}{x}=-c\cdot\left(\lim_{x\to\infty}\frac{\ln x}{\sqrt{x}}\right)=\frac{\infty}{\infty}$$

Since this is an indeterminate form, L'Hospital's rule must be invoked:

$$-c\cdot\lim_{x\to\infty}\frac{\frac{d}{dx}[\ln(x)]}{\frac{d}{dx}\left[\sqrt{x}\right]}=-c\cdot\lim_{x\to\infty}\frac{2}{\sqrt{x}}=-c\cdot 0=0$$

So now we have found a usable form of a baseline GUC model:

$$f_b(x)=a\cdot x-c\cdot\sqrt{x}\cdot\ln x$$

This function may be used to model the normalized[10] cost of any category of facility. It will reflect the cost of an average facility and is not corrected for technology enhancements or other unique facility characteristics since these additional variable inputs are not collected. The model could be modified to accept these variables if they became available in the future.

Escalation

Since our cost data is influenced by time, an appropriate correction factor must be included. One appropriate form of the escalation function is simply the continuous compounding rate formula, $g(t)=e^r$, where ***r*** is the interest (or escalation) rate and ***t*** is the time variable. Since the escalation rate changes through time, we may modify the formula to a more applicable form:

$$g(t)=e^{r(t)}$$

Where ***r(t)*** is a polynomial function in the time domain that captures the escalation rate through time. To dampen wild fluctuations between data points, the function is arbitrarily limited to a cubic polynomial.

$$r(t)=\sum_{i=1}^{3}\beta_i\cdot t^i$$

Where the β_i's are the coefficients to the cubic equation.

So the overall modeling function becomes:

$$f(x,t)=g(t)\cdot f_b(x)$$

$$f(x,t)=e^{(\beta_1 t+\beta_2 t^2+\beta_3 t^3)}\cdot\left[ax-c\left(\sqrt{x}\right)\ln x\right]$$

Area Cost Factors

Once all models are completed, an ANOVA procedure can be run against the error variances by U.S. State (*S*). If the error variance is significant, then a table of ACF adjustments can be created to improve model accuracy. So the final form of the model becomes:

$$F(x,t,S)=ACF(S)\cdot\ f(x,t)$$

[10] Normalized for time-value of money and area cost variances

Equation 1:

$$F(x,t,S) = ACF(S) \cdot e^{(\beta_1 t + \beta_2 t^2 + \beta_3 t^3)} \cdot \left[ax - c\left(\sqrt{x}\right)\ln x\right]$$

Procedure

The models were built using non-linear modeling techniques. Specifically, MathCad's version 15.0 software package was used for the calculations. An initial guess was made for all unknown coefficient values and the sum of squared errors (SSE) was calculated. SSE was fed into MathCad's "*Minimize*" function and the coefficients were adjusted for minimum error. The *Minimize* function uses the Conjugate Gradient[11] method for finding function roots.

RESULTS

As presented in the Background section, this analysis examined the entire HII database of AF MILCON projects from FY03-13 (588 projects). After filtering through the CONUS[12], New Construction projects only, 10 FAC codes were found that contained a set of at least 10 new facilities. I chose these FACs to test my model.

FAC 1412: Aviation Operations Bldg

The HII database listed 48 projects and 52 newly constructed facilities under this FAC. However, cost data from only 33 of the facilities was used to construct the models due to problems in the database. Some of the problems noted were:

1. Duplicate project (CZQZ 073014, …)
2. Significant differences between DD1391 and HII data (PDPG020143)
3. CatCode not part of the FAC (FBNV 113002 & others)
4. Support costs added to facility costs (WACC073020)
5. Project costs are unbalanced (ACC093010)
6. Dissimilar FAC coded facilities built together under a single facility cost (VDYD050107/8)
7. Ground Control Station facility listed as a Squadron Ops facility (LKTC063102/3R2)
8. Mis-categorization of CatCodes (multiple projects)

Model Parameters

The coefficients for the FAC 1412 model are:

$$\begin{bmatrix} a \\ c \\ \beta_1 \\ \beta_2 \\ \beta_3 \end{bmatrix} = \begin{bmatrix} 1212.19687 \\ 175.65533526 \\ -0.0113731 \\ -0.01313386 \\ -7.94157718 \cdot 10^{-4} \end{bmatrix}$$

The coefficient of determination, or r^2 value, provides a measure of how much error variance is explained by the model. For the FAC 1412 model, 94% of the error is explained by the model (i.e., $r^2 = 0.944$). The desired target for a "satisfactory" model is an r^2 value above 0.80.

[11] See Numerical Recipes in FORTRAN, the Art of Scientific Computing, 2nd Ed., pp. 413-418

[12] CONUS, or "CONtinental United States," has traditionally meant the lower 48 contiguous States. This is the meaning of CONUS in this report. I.e., Alaska and Hawaii MILCON projects are excluded.

Figure 5: FAC 1412 SF & Total Cost Models

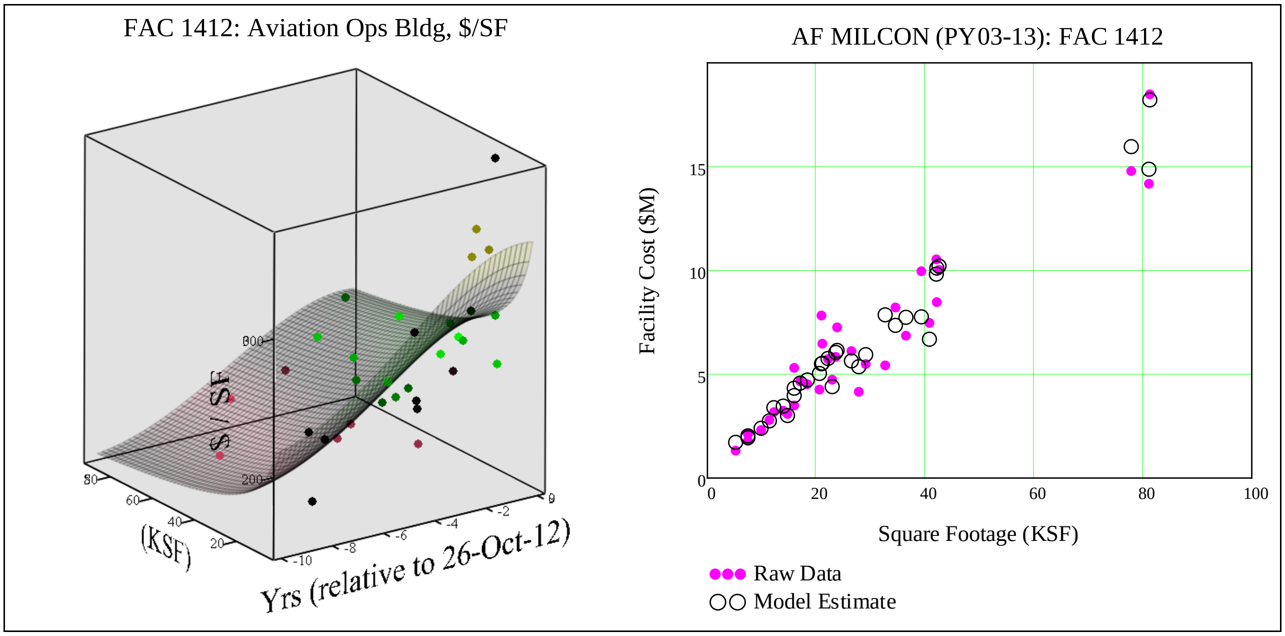
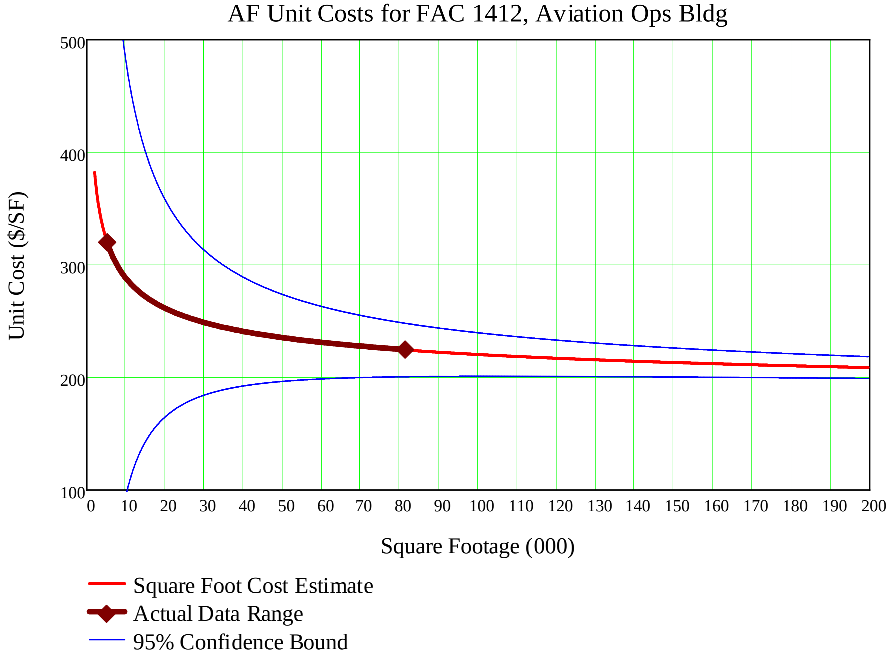


Figure 6: FAC 1412 Baseline Model



Comparative Performance

The modeling is more accurate than the FGE and appears to be more accurate than the GUC. Comparison with the FGE is straight-forward. The FGE was developed specifically for each project and is a direct, “apples-to-apples” comparison. Comparison with the GUC, however, poses a few difficulties. First, GUC values are updated every year. Since I did not have access to prior year GUC values, I attempted to adjust them for inflation. But the SPI only goes back to

2007. Therefore, I used the long-term inflation rates published by the National Institute of Standards and Technology in their annual energy rate supplement.[13] Published 2012 ACF values from UFC 3-701-01 (Table 4.1) were used for spatial correction. The results are listed in the following Table 1.

Table 1: FAC 1412, Comparative Accuracy

	FAC Model	FGE	GUC
Average error, or bias:	-0.1%	9.5%	-5.9%
Data Spread (avg std dev, σ):	15.7%	24.5%	22.7%

As you can see, the FAC 1412 model maps the historical data value tighter than either the GUC or FGE.

FAC 1444: Miscellaneous Operations Support Bldg

The AF built 19 FAC 1444 facilities over the 10-yr analysis period but only 12 were used to build the model. Seven project facilities had data discrepancies similar to those described for FAC 1412.

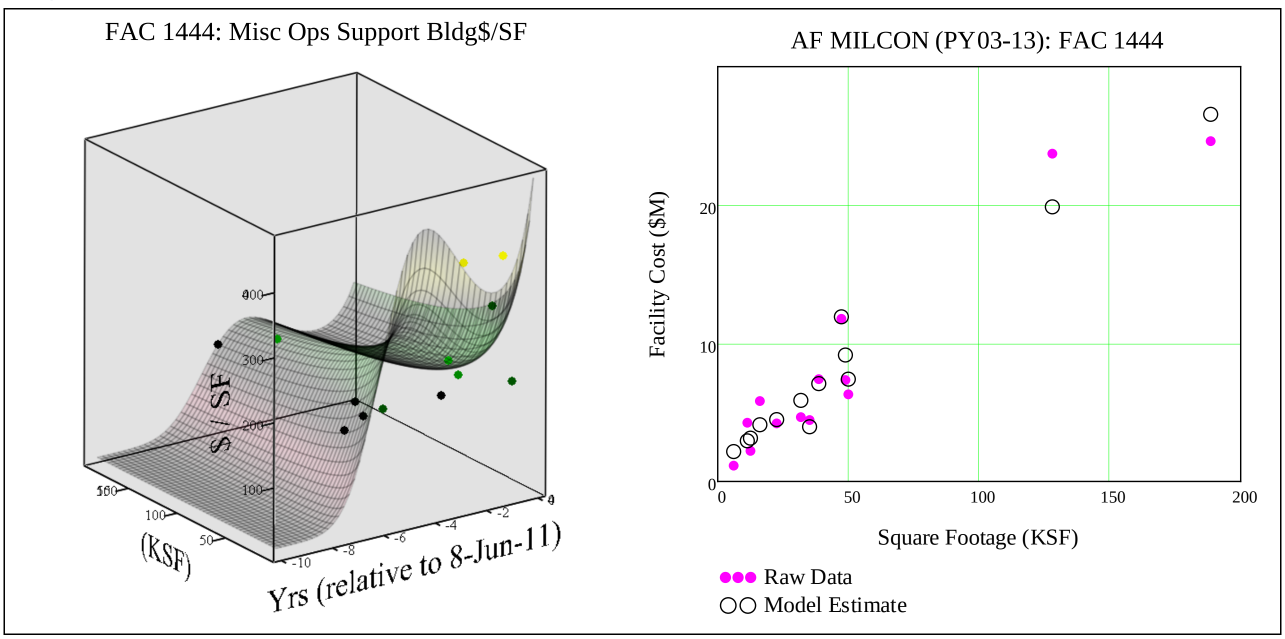
Model Parameters

The coefficients for the FAC 1444 model are:

$$\begin{bmatrix} a \\ c \\ \beta_1 \\ \beta_2 \\ \beta_3 \end{bmatrix} = \begin{bmatrix} 3562.01279 \\ 73.52975291 \\ 0.63682629 \\ 0.28860421 \\ 0.03376811 \end{bmatrix}$$

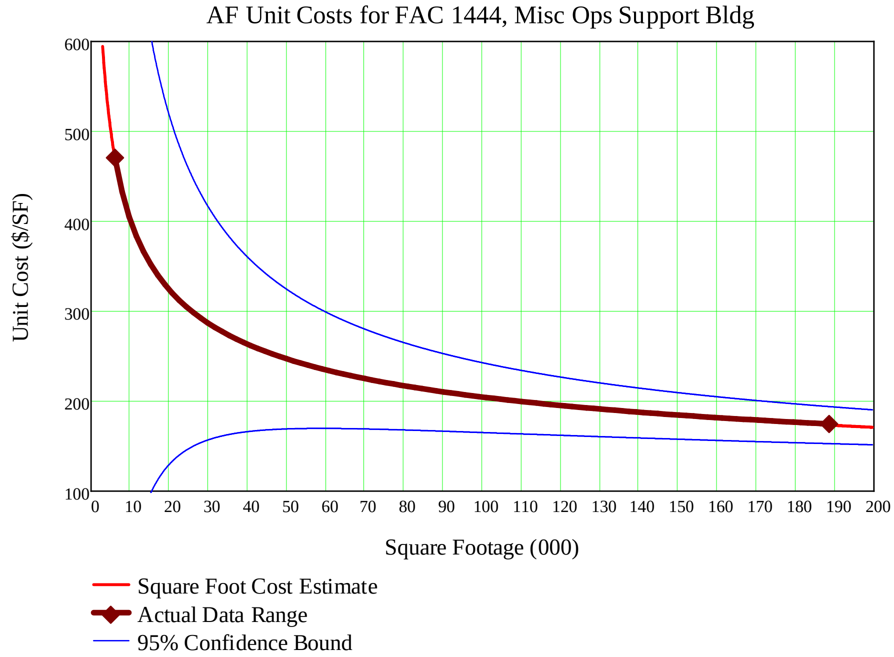
For the FAC 1444 model, $\boldsymbol{r^2}$ = 0.953 (i.e., 95.3% the error is explained by the model).

Figure 7: FAC 1444 SF & Total Cost Models



[13] The latest issue is:
NISTIR 85-3273-28, Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis -- 2013

Figure 8: FAC 1444 Baseline Model



Comparative Performance

The FAC Model provides a better estimate than the FGE but is only marginally better than the GUC method (less bias but bigger data spread).

Table 2: FAC 1444, Comparative Accuracy

	FAC Model	FGE	GUC
Average error, or bias:	0.7%	15.2%	10.2%
Data Spread (avg std dev, σ):	24.3%	30.4%	34.6%

FAC 1711: General Purpose Instruction Bldg

The HII database held 53 AF FAC 1711 facilities within the 10-yr analysis period but only 28 were used to build the model. Twenty-five (25) project facilities had data discrepancies similar to those described on page 10. Most were mis-categorized or were duplicate projects.

Of the 28 constructed facilities, 10 were AF CatCode 171211, Flight Training Classroom. This CatCoded facility was found to be significantly different than the remaining FAC 1711 facilities. A single-factor ANOVA test found that 171211 facilities had less than a 1% chance of belonging to the same distribution as the others. Therefore, essentially two models were built for this FAC.

Model Parameters

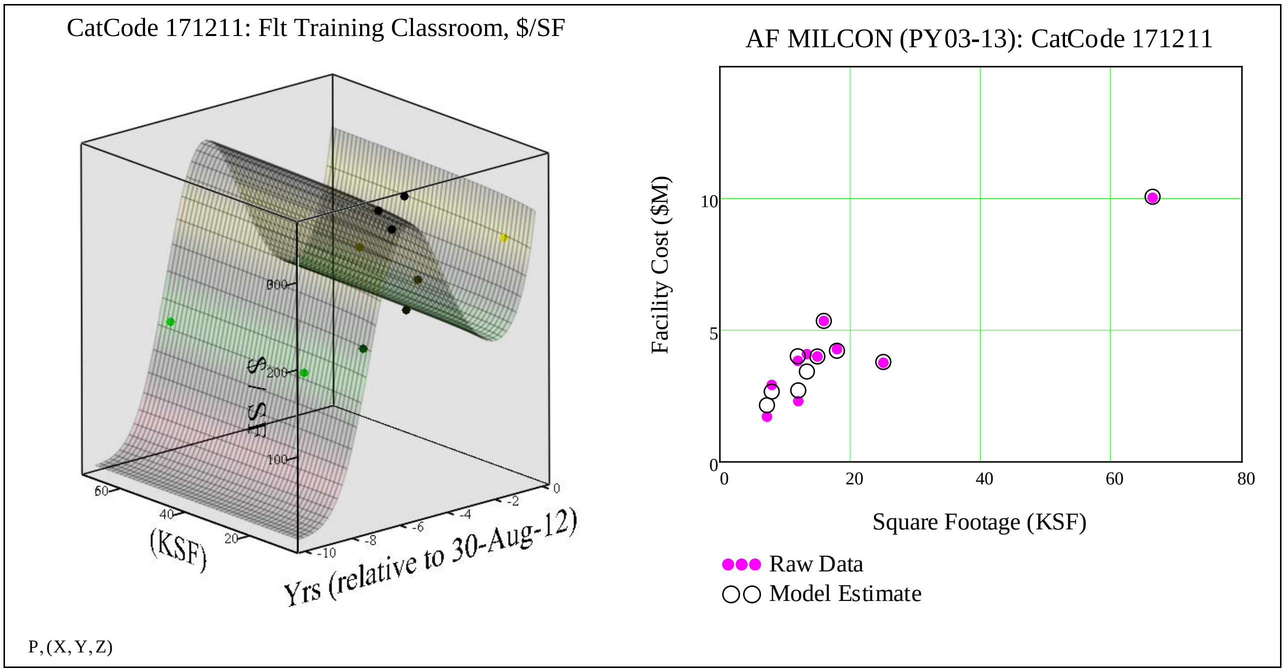
The coefficients for the FAC 1711 model are:

CatCode = 171211: $$\begin{bmatrix} a \\ c \\ \beta_1 \\ \beta_2 \\ \beta_3 \end{bmatrix} = \begin{bmatrix} -180.62528361 \\ 321.61829666 \\ 0.77718446 \\ 0.29995439 \\ 0.02842228 \end{bmatrix}$$

$$\text{CatCode} \neq 171211: \quad \begin{bmatrix} a \\ c \\ \beta_1 \\ \beta_2 \\ \beta_3 \end{bmatrix} = \begin{bmatrix} 727.01498926 \\ 201.28764771 \\ -0.01270646 \\ -0.04321536 \\ -0.00457085129 \end{bmatrix}$$

For FAC 1711, r^2 = 0.981 for the CatCode 171211 model and r^2 = 0.988 for the CatCode ≠ 171211 model.

Figure 9: FAC 1711 SF & Total Cost Models



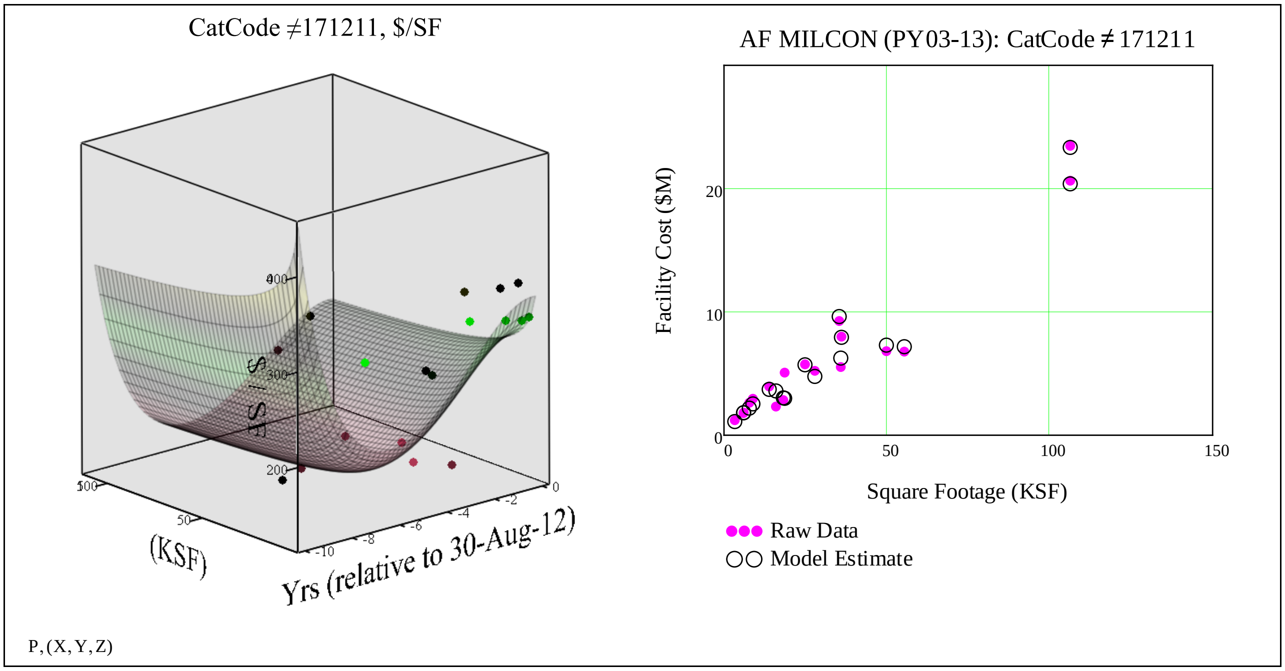
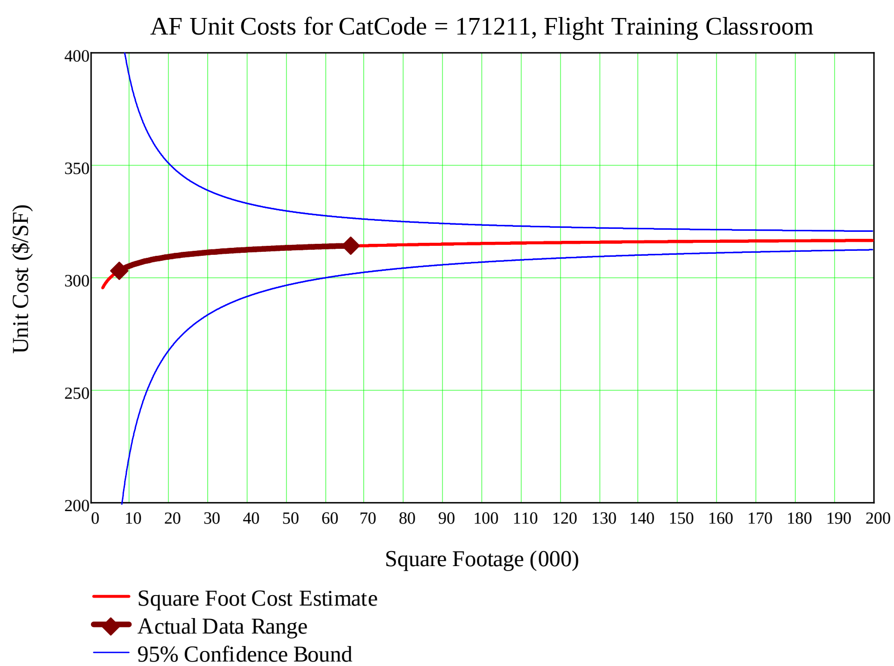
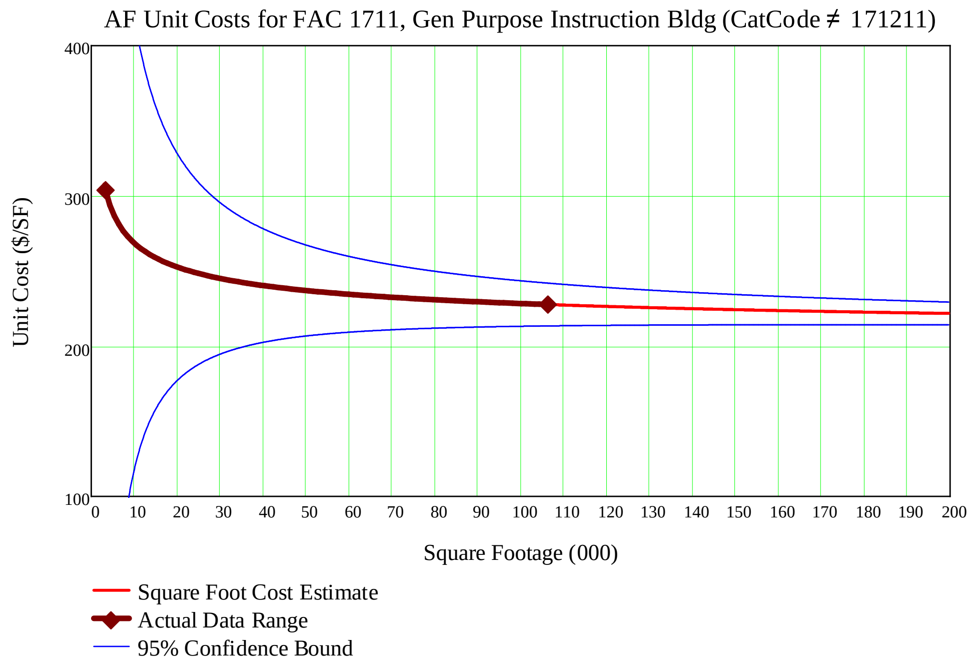


Figure 10: FAC 1711 Baseline Models





Comparative Performance

Table 3: FAC 1711, Comparative Accuracy

	FAC Model	FGE	GUC
Average error, or bias:	-0.4%	-7.9%	-4.4%
Data Spread (avg std dev, σ):	8.7% 12.5%	22.7%	27.1%

FAC 1721: Flight Simulator Facility

The AF built 21 Flight Simulator Facilities over the 10-yr analysis period and all were used to build the model. No serious data discrepancies were found in this data set.

Model Parameters

The coefficients for the FAC 1444 model are:

$$\begin{bmatrix} a \\ c \\ \beta_1 \\ \beta_2 \\ \beta_3 \end{bmatrix} = \begin{bmatrix} 1284.31728 \\ 181.3977083 \\ -0.2095887 \\ -0.05920616 \\ -0.003716746 \end{bmatrix}$$

For the FAC 1721 model, $\boldsymbol{r}^2$ = 0.981 (i.e., 98.1% the error is explained by the model).

Figure 11: FAC 1721 SF & Total Cost Models

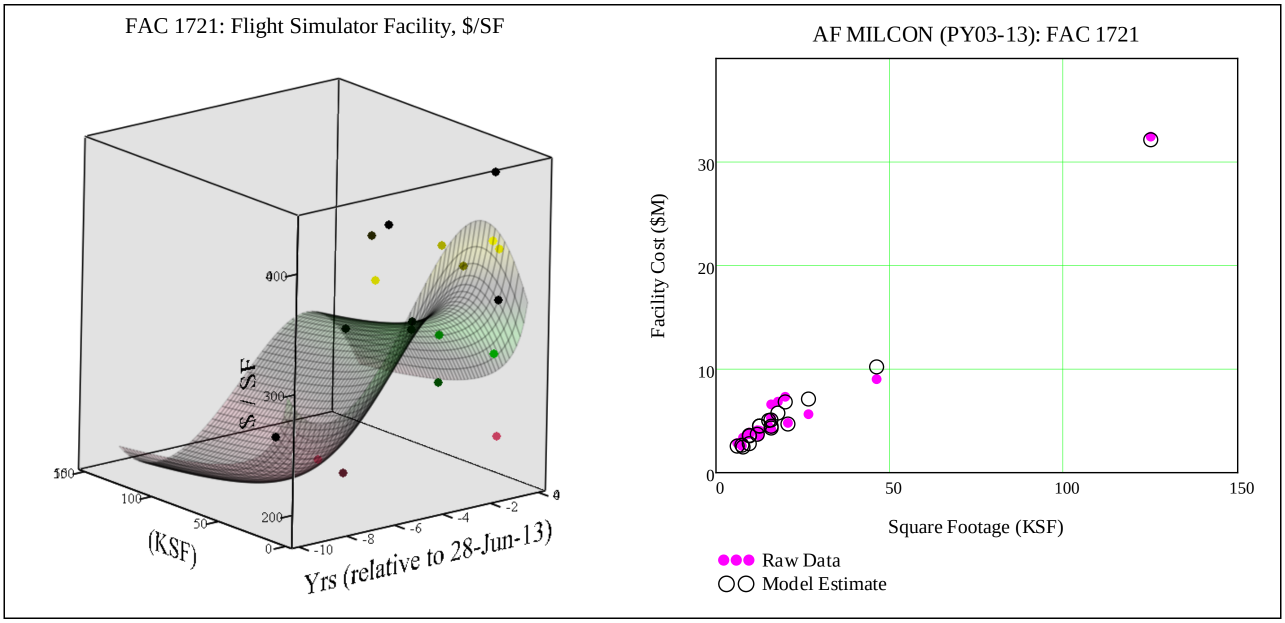
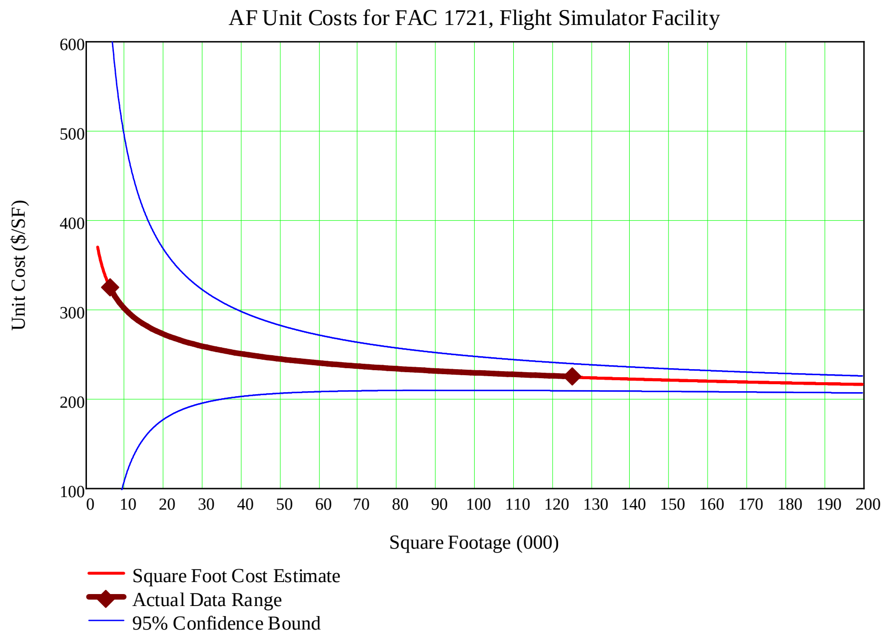


Figure 12: FAC 1721 Baseline Model



Comparative Performance

The FAC Model provides a more accurate estimate than the FGE and GUC but the FGE has less variability (i.e., FAC Model has less bias but bigger data spread).

Table 4: FAC 1721, Comparative Accuracy

	FAC Model	FGE	GUC
Average error, or bias:	-1.0%	4.5%	6.0%
Data Spread (avg std dev, σ):	16.6%	15.2%	19.1%

FAC 2111: Aircraft Maintenance Hangar

The AF built 34 facilities over the 10-yr analysis period that were identified as aircraft maintenance hangars. However, 13 of these project facilities contained discrepancies that precluded them from being used in the model. The primary discrepancies were:

1. Unbalanced project costs;
2. Partial facility mods or additions (i.e., tail-in enclosure)
3. Improper CatCode assignment (FAC 2111 assigned to pump house & admin space)

However, the remaining data was highly congruent and produced a satisfactory model..

Model Parameters

The coefficients for the FAC 2111 model are: $\begin{bmatrix} a \\ c \\ \beta_1 \\ \beta_2 \\ \beta_3 \end{bmatrix} = \begin{bmatrix} 913.28026415 \\ 218.65092642 \\ 0.01380057 \\ -4.20672408 \times 10^{-4} \\ 2.4596905 \times 10^{-4} \end{bmatrix}$

For the FAC 2111 model, $\boldsymbol{r}^2$ = 0.952 (i.e., 95.2% the error is explained by the model).

Figure 13: FAC 2111 SF & Total Cost Models

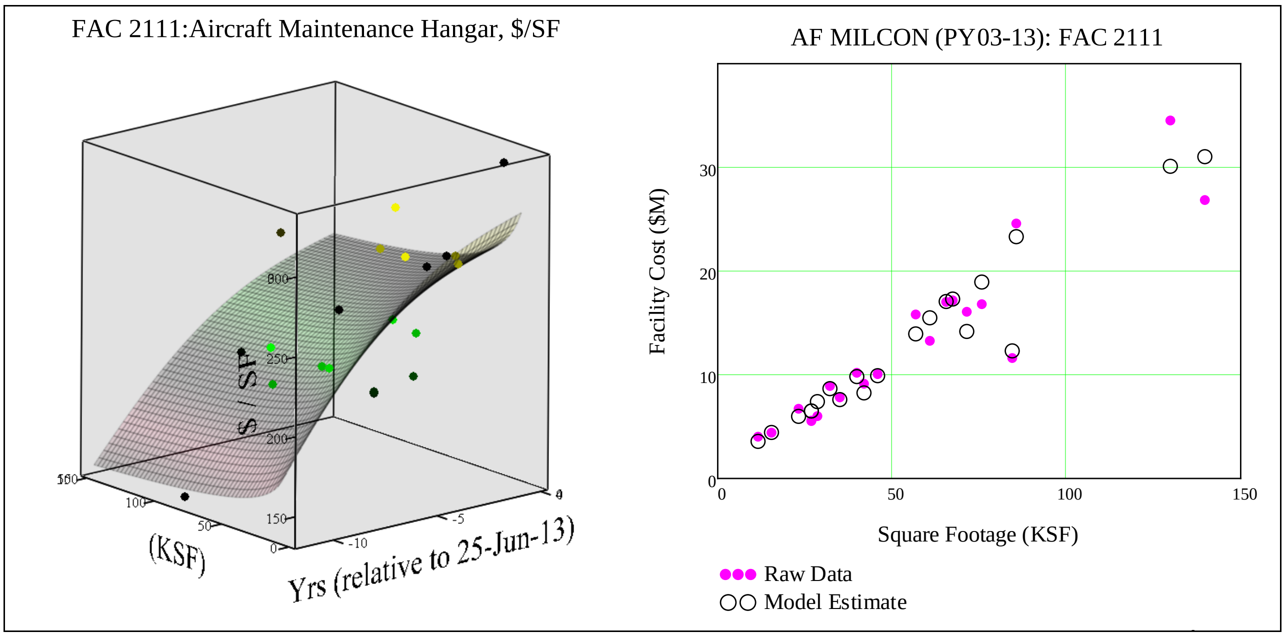
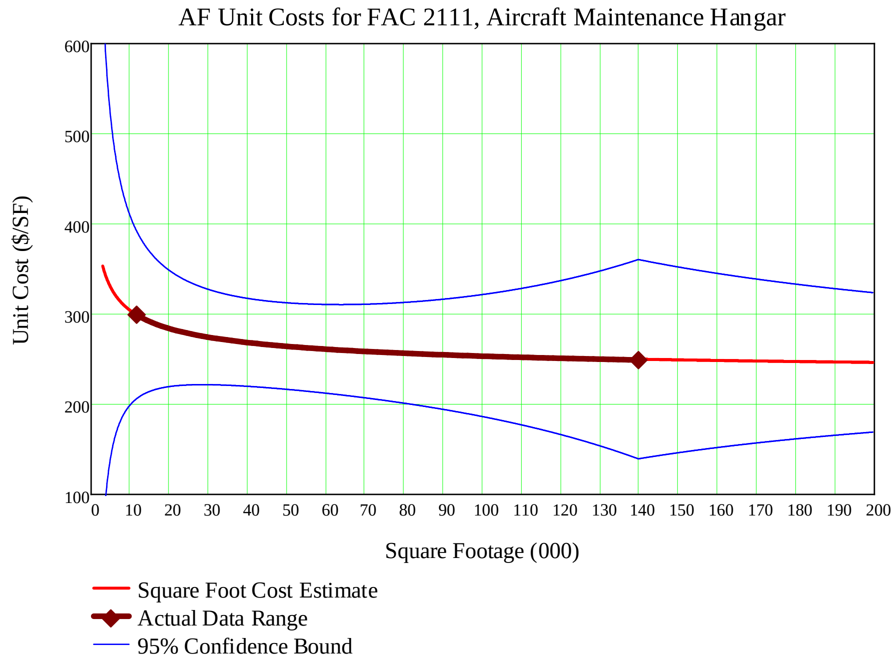


Figure 14: FAC 2111 Baseline Model



Comparative Performance

The FAC Model provides a more accurate estimate than the FGE and GUC.

Table 5: FAC 2111, Comparative Accuracy

	FAC Model	FGE	GUC
Average error, or bias:	0.1%	-0.7%	-8.2%
Data Spread (avg std dev, σ):	15.3%	34.8%	25.3%

FAC 4221: Ammunition Storage

The AF built 21 facilities over the 10-yr analysis period that were identified as ammunition storage facilities. However, 7 of these project facilities contained discrepancies that precluded them from being used in the model. The primary discrepancies were:

1. Cost discrepancies between HII and the DD1391;
2. Conflicting square footage data
3. Improper CatCode assignment

However, the remaining data was highly congruent and produced a satisfactory model..

Model Parameters

The coefficients for the FAC 4221 model are:

$$\begin{bmatrix} a \\ c \\ \beta_1 \\ \beta_2 \\ \beta_3 \end{bmatrix} = \begin{bmatrix} 2405.50628 \\ -131.74884351 \\ -0.4419326 \\ -0.2407559 \\ -0.03318142 \end{bmatrix}$$

For the FAC 4221 model, r^2 = 0.888 (i.e., 88.8% the error is explained by the model).

Figure 15: FAC 4221 SF & Total Cost Models

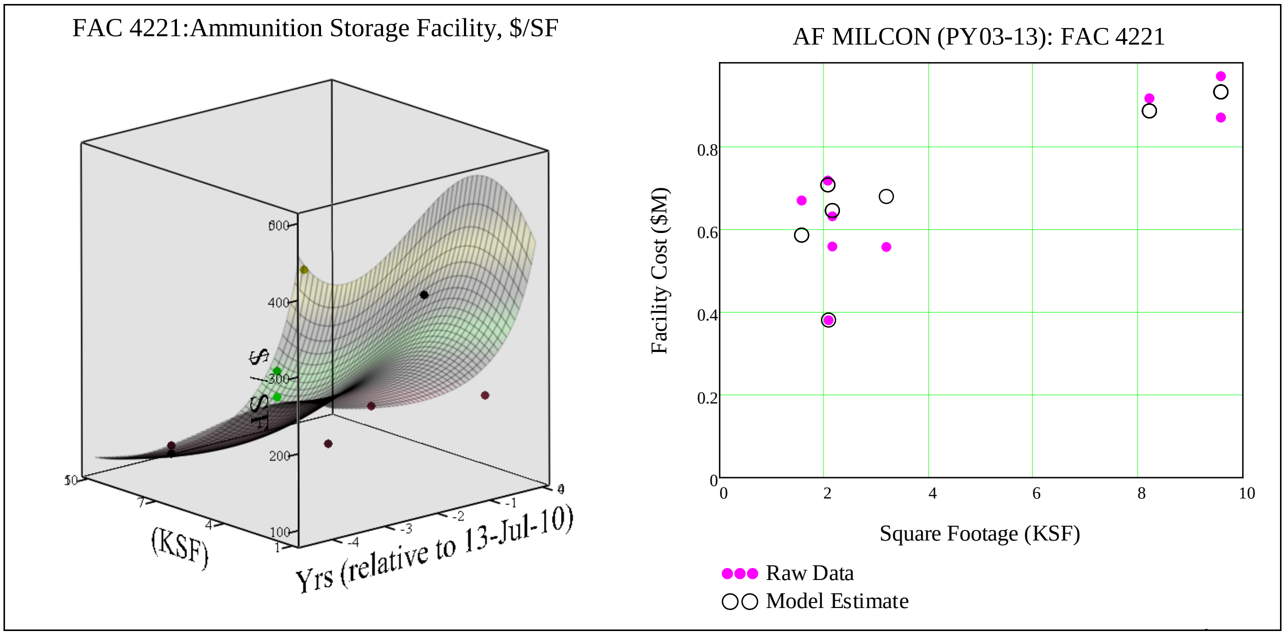
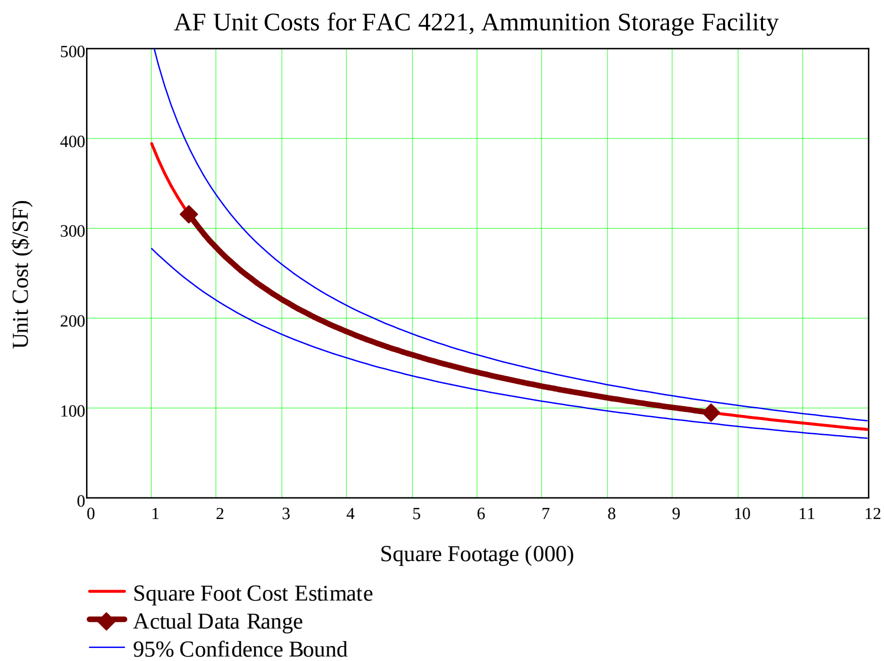


Figure 16: FAC 4221 Baseline Model



Comparative Performance

The FAC Model provides a more accurate estimate than the FGE and GUC. The GUC estimate is particularly poor.

Table 6: FAC 4221, Comparative Accuracy

	FAC Model	FGE	GUC
Average error, or bias:	-0.1%	-12.8%	44.8%
Data Spread (avg std dev, σ):	9.4%	31.4%	94.1%

FAC 4421: Covered Storage Building

The AF built 20 facilities over the 10-yr analysis period that were identified as covered storage buildings. However, 6 of these project facilities contained discrepancies that precluded them from being used in the model. The primary discrepancies were:

1. Unbalanced project costs;
2. Partial facility mods or additions
3. Improper CatCode assignment

Model Parameters

The coefficients for the FAC 4421 model are: $\begin{bmatrix} a \\ c \\ \beta_1 \\ \beta_2 \\ \beta_3 \end{bmatrix} = \begin{bmatrix} 1089.96464 \\ 81.89766244 \\ 0.14220168 \\ 0.04729383 \\ 3.97685024 \times 10^{-3} \end{bmatrix}$

For the FAC 4421 model, r^2 = 0.997 (i.e., 99.7% the error is explained by the model).

Figure 17: FAC 4421 SF & Total Cost Models

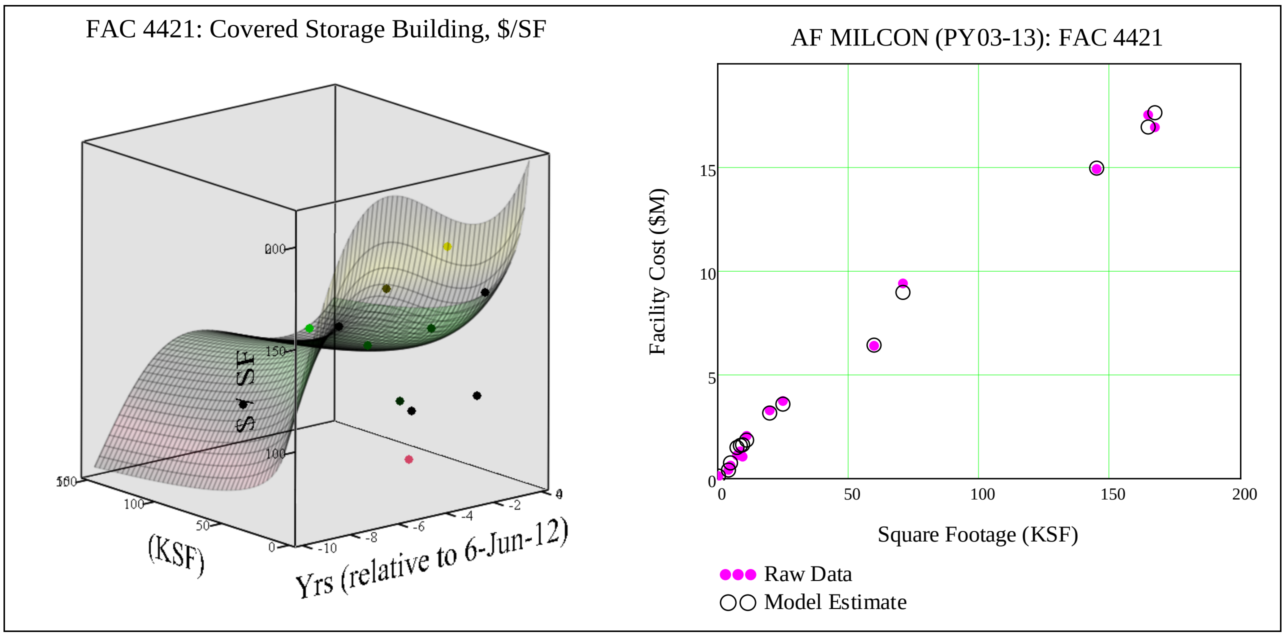
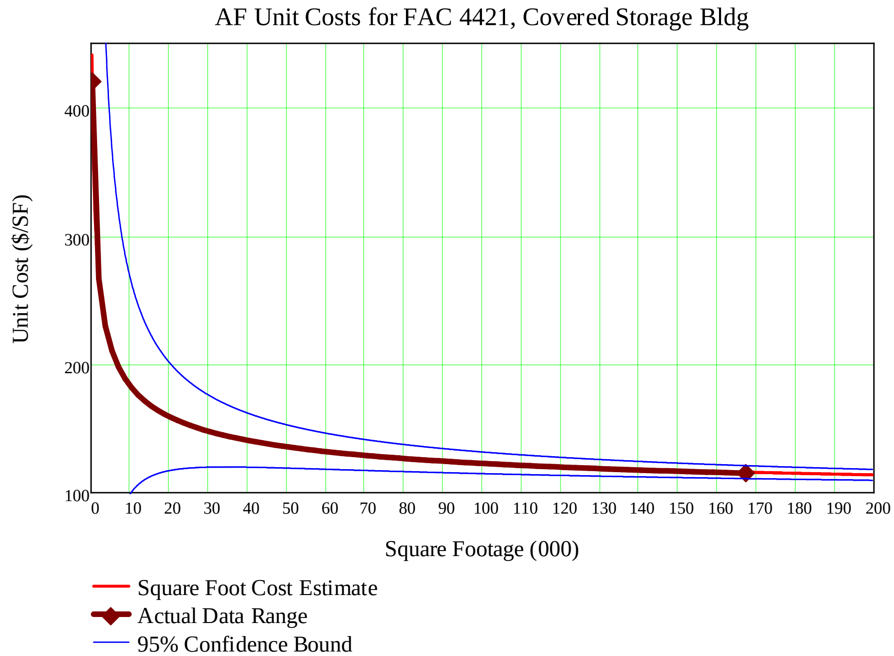


Figure 18: FAC 4421 Baseline Model



Comparative Performance

The FAC Model provides a more accurate estimate than the FGE and GUC.

Table 7: FAC 4421, Comparative Accuracy

	FAC Model	FGE	GUC
Average error, or bias:	0.8%	10.2%	-21.7%
Data Spread (std dev, σ):	7.8%	28.3%	34.9%

FAC 6100: General Administrative Building

The AF built 42 facilities over the 10-yr analysis period that were identified as General Administrative buildings. However, 16 of these project facilities contained discrepancies that precluded them from being used in the model. The primary discrepancies were:

1. Unbalanced project costs;
2. Partial facility mods or additions
3. Improper CatCode assignment
4. Missing project cost data
5. Duplicate project entries
6. DD1391 identifies the building as either a SCIF, EMP hardened, and/or EF-5 tornado resistant facility

Of the 26 constructed facilities, 16 were HQ facilities (CatCode 6102XX). HQ facilities were found to be significantly different than the remaining FAC 6100 facilities. A single-factor ANOVA test found that HQ facilities had approximately a 5% chance of belonging to the same distribution as the others. Therefore, essentially two models were built for this FAC.

Model Parameters

The coefficients for the CatCode 6102XX model are:

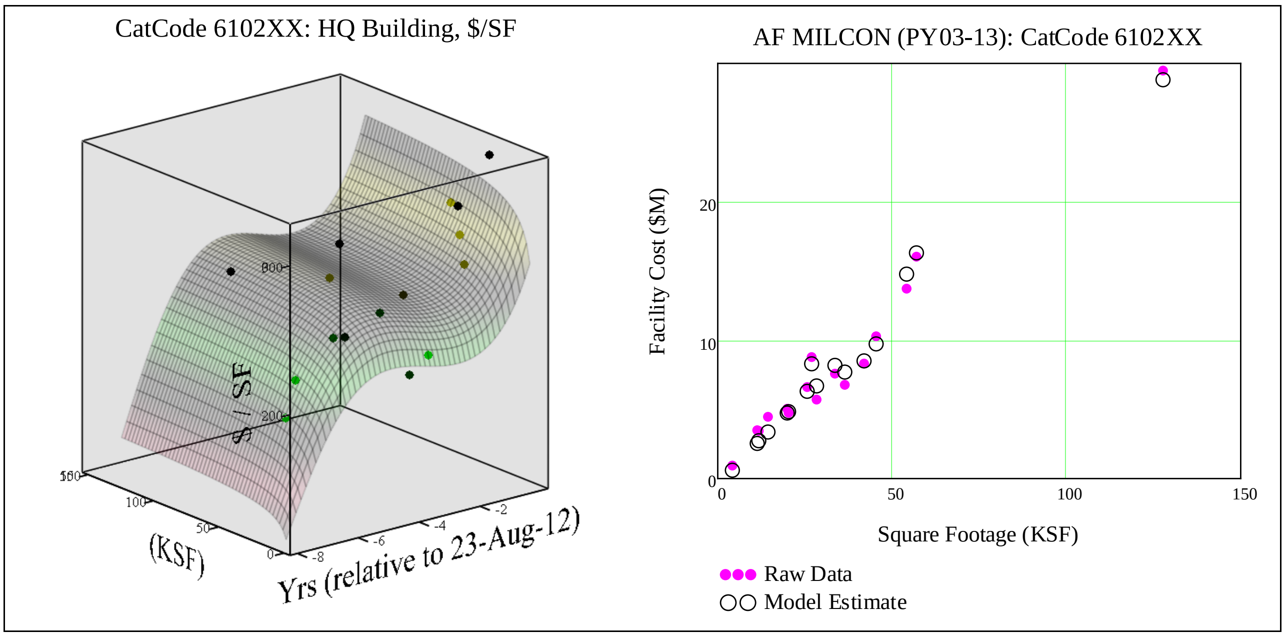
$$\begin{bmatrix} a \\ c \\ \beta_1 \\ \beta_2 \\ \beta_3 \end{bmatrix} = \begin{bmatrix} -564.16252629 \\ 328.87832032 \\ 0.24670189 \\ 0.07937267 \\ 7.67450174 \times 10^{-3} \end{bmatrix}$$

The coefficients for the non-HQ FAC 6100 model are:

$$\begin{bmatrix} a \\ c \\ \beta_1 \\ \beta_2 \\ \beta_3 \end{bmatrix} = \begin{bmatrix} 3855.01365 \\ 6.77841527 \\ -0.09522388 \\ -0.01903681 \\ -2.25364078 \times 10^{-7} \end{bmatrix}$$

For the CatCode 6102XX model, r^2 = 0.990 (i.e., 99.0% of the error is explained by the model). For the remaining non-HQ FAC 6100 facilities, r^2 = 0.952 (i.e., 95.2% of the error is explained by the model).

Figure 19: FAC 6100 SF & Total Cost Models



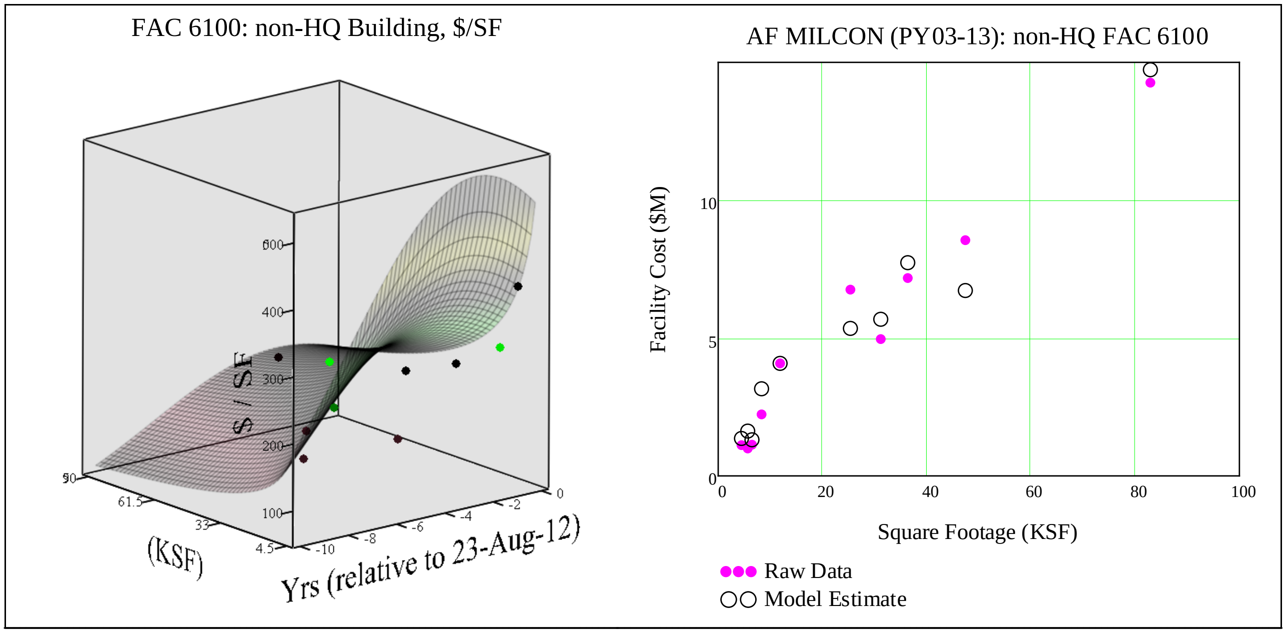
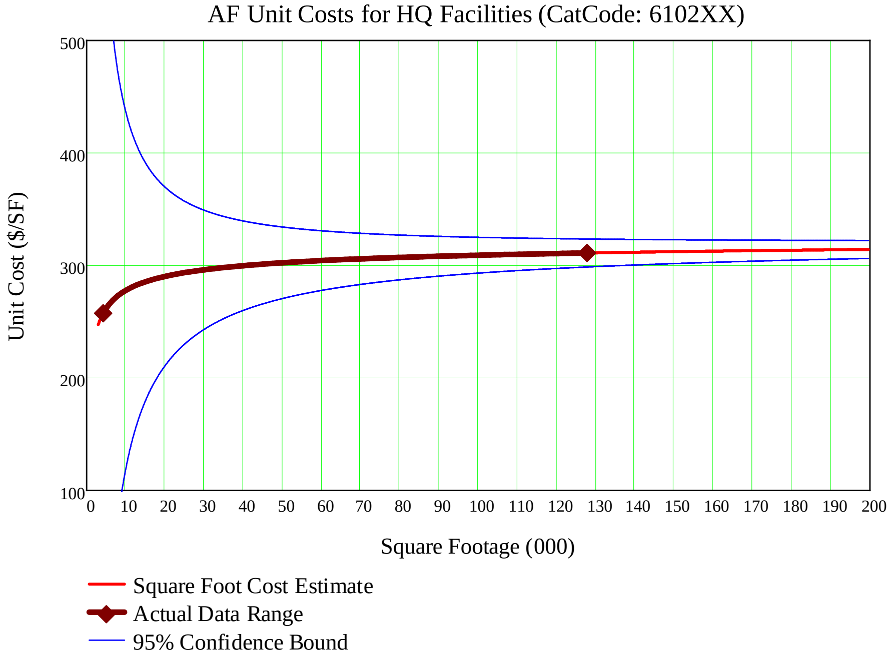
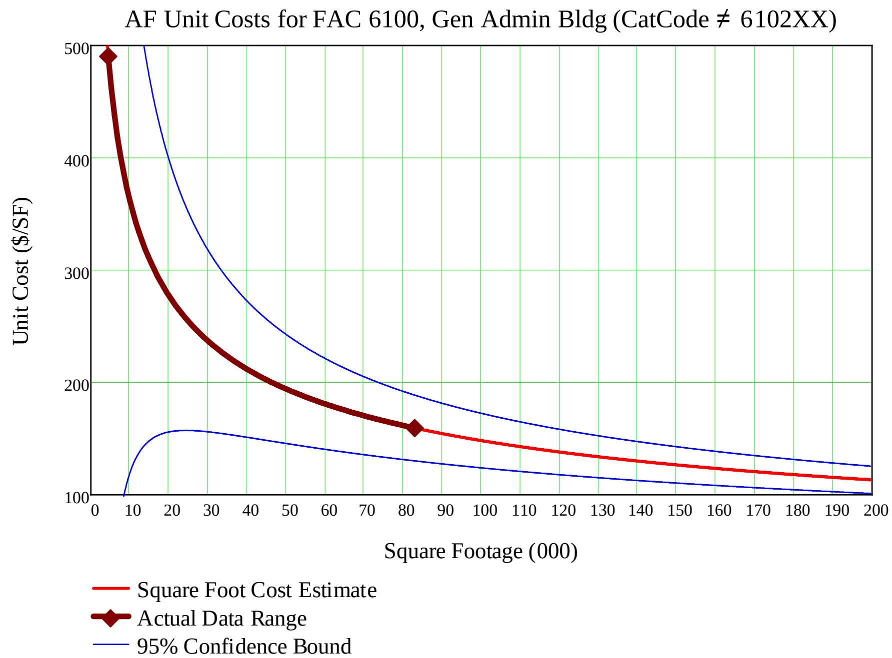


Figure 20: FAC 6100 Baseline Models





Comparative Performance

The FAC Model provides a more accurate estimate than the FGE and GUC.

Table 8: FAC 6100, Comparative Accuracy

	FAC Model	FGE	GUC
Average error, or bias:	-0.5%	5.3%	-10.7%
Data Spread (avg std dev, σ):	9.7% 24.5%	21.1%	27.4%

FAC 7210: Enlisted Unaccompanied Housing

The AF built 30 facilities over the 10-yr analysis period that were identified as Enlisted Unaccompanied Housing. However, 8 of these project facilities contained discrepancies that precluded them from being used in the model. The primary discrepancies were:

1. Unbalanced project costs;
2. Partial facility mods or additions
3. Improper CatCode assignment

Model Parameters

The coefficients for the FAC 7210 model are:

$$\begin{bmatrix} a \\ c \\ \beta_1 \\ \beta_2 \\ \beta_3 \end{bmatrix} = \begin{bmatrix} 4760.09125 \\ 13.79993973 \\ -0.0192246 \\ -2.62558565 \times 10^{-3} \\ 2.53087912 \times 10^{-4} \end{bmatrix}$$

For the FAC 7210 model, r^2 = 0.904.

Figure 21: FAC 7210 SF & Total Cost Models

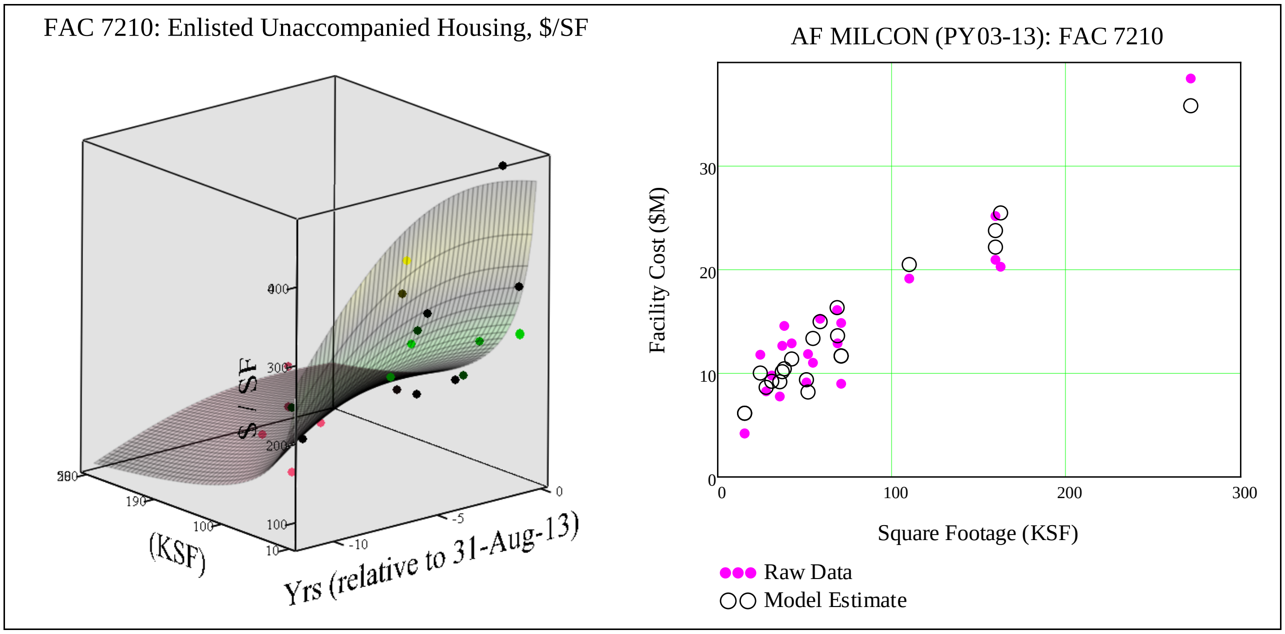
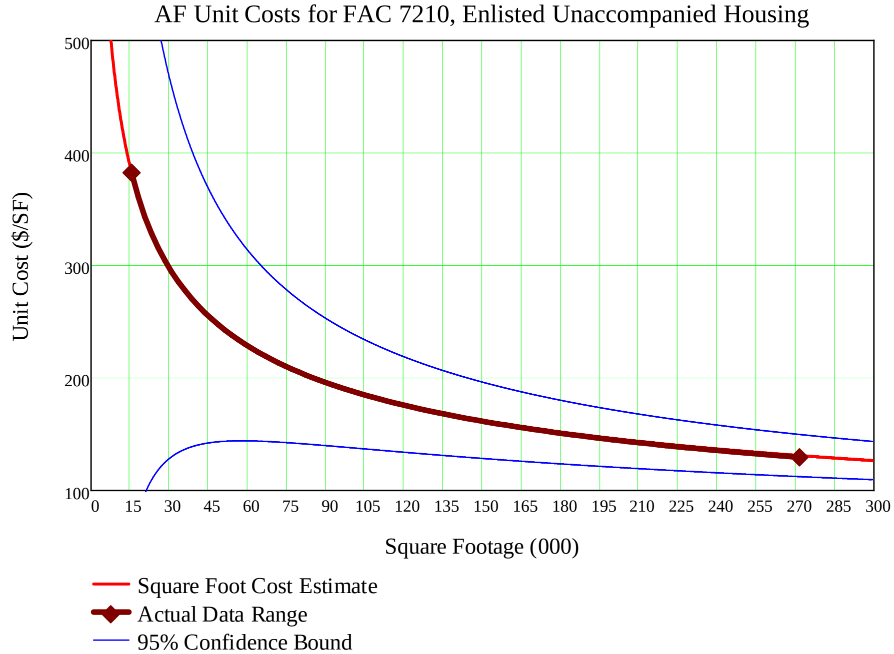


Figure 22: FAC 7210 Baseline Model



Comparative Performance

The FAC Model provides a more accurate estimate than the FGE and GUC.

Table 9: FAC 4421, Comparative Accuracy

	FAC Model	FGE	GUC
Average error, or bias:	-0.6%	12.4%	-21.3%
Data Spread (std dev, σ):	18.7%	28.5%	27.7%

FAC 7371: Nursery & Child Care Facility

The AF built 19 facilities over the 10-yr analysis period that were identified as nursery & child care facilities. However, 2 of these project facilities contained discrepancies that precluded them from being used in the model. The two discrepancies were:

1. Partial facility mods or additions
2. Improper CatCode assignment

Model Parameters

The coefficients for the FAC 7371 model are:

$$\begin{bmatrix} a \\ c \\ \beta_1 \\ \beta_2 \\ \beta_3 \end{bmatrix} = \begin{bmatrix} 2247.12126 \\ 111.3579046 \\ 0.05388655 \\ 0.01543189 \\ 1.6972233 \times 10^{-3} \end{bmatrix}$$

For the FAC 7371 model, $r^2 = 0.945$.

Figure 23: FAC 7371 SF & Total Cost Models

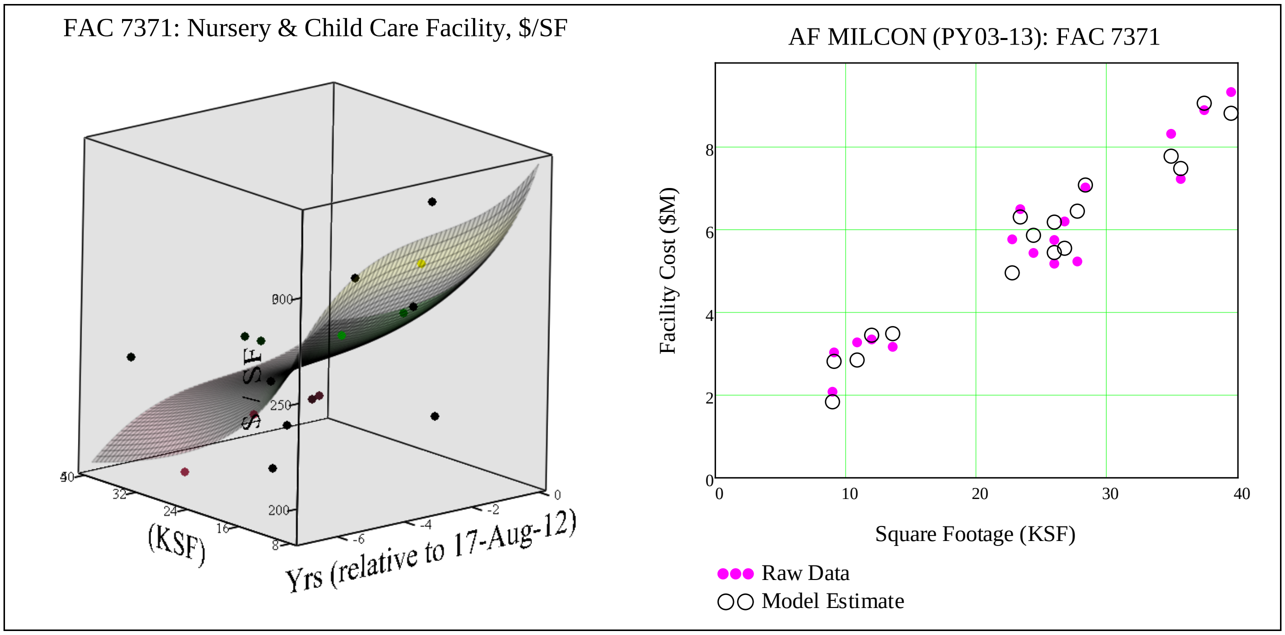
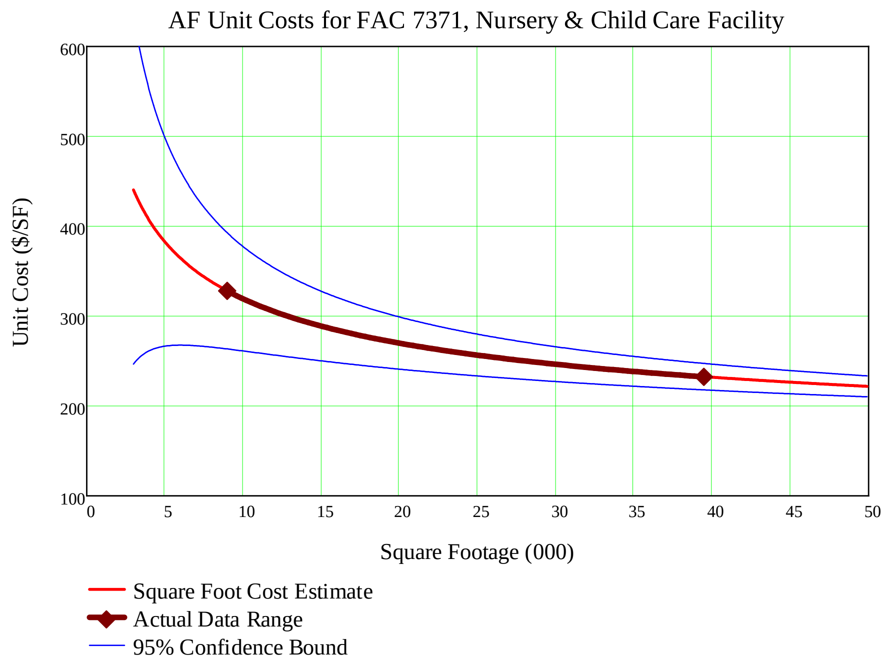


Figure 24: FAC 7371 Baseline Model



Comparative Performance

The FAC Model provides a more accurate estimate than the FGE and GUC.

Table 10: FAC 7371, Comparative Accuracy

	FAC Model	FGE	GUC
Average error, or bias:	-0.4%	15.6%	-1.5%
Data Spread (std dev, σ):	9.8%	26.7%	19.1%

Summary

The FAC models exceeded the accuracy of the Facility Government Estimate (FGE) and the Guidance Unit Cost (GUC) estimates (calculated per UFC 3-701-1). The model bias is significantly lower than either the FGE or the GUC models and the standard deviation is almost ½ of the FGE and 60% less than the GUC.

Table 11: Model Performance Summary

FAC	FAC Model		FGE Model		GUC Model	
	bias	*Avg. Std. Dev.*	*bias*	*Avg. Std. Dev.*	*bias*	*Avg. Std. Dev.*
1412	-0.14%	15.7%	9.50%	24.5%	-5.85%	22.7%
1444	0.71%	24.3%	15.22%	30.4%	10.20%	34.6%
1711	-0.40%	8.7%	-7.90%	22.7%	-4.42%	27.1%
		12.5%				
1721	-0.95%	16.6%	4.45%	15.2%	5.98%	19.1%
2111	0.06%	15.3%	-0.67%	34.8%	-8.16%	25.3%
4221	-0.06%	9.4%	-12.84%	31.4%	44.80%	94.1%
4421	0.82%	7.8%	10.16%	28.3%	-21.68%	34.9%
6100	-0.48%	9.7%	5.31%	21.1%	-10.66%	27.4%

FAC	FAC Model		FGE Model		GUC Model	
	bias	***Avg. Std. Dev.***	***bias***	***Avg. Std. Dev.***	***bias***	***Avg. Std. Dev.***
		24.5%				
7210	-0.61%	18.7%	12.35%	28.5%	-21.34%	27.7%
7371	-0.35%	9.0%	15.60%	24.8%	-1.51%	17.6%
Total[14]	**-1.40%**	**53.4%**	**51.18%**	**84.5%**	**-12.64%**	**123.9%**

CONCLUSION

Non-linear models should be explored further as a substitute for traditional GUC annual updates. The Tri-Service Cost Engineering Community would benefit by improved accuracy for MILCON programming estimates and less stringent data requirements for annual updates.

You may contact the author through the AFCEC Reach Back Center, (850) 283-6995, or AFCEC.RBC@us.af.mil.

[14] The "Total" can be interpreted in the following way: if the AF were to build a facility from each FAC in one year, the combined bias of all facilities would be the sum of the individual bias's and the Std Dev, σ, of this probability distribution would be the square root of the sum of the individual squared Std Devs, σ^2. I.e., $\boldsymbol{bias_{tot}} = \sum_i \boldsymbol{bias_i}$, and $\boldsymbol{\sigma_{tot}} = \sqrt{\sum_i (\boldsymbol{\sigma_i})^2}$