Contractually Speaking: The Story of DoD Contract Vehicles

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Abstract

In 2017, the Department of Defense (DoD) contracted $320 billion of effort and consistently procures more than any other United States government agency. An important part of the procurement process is agreeing on a contract with industry. As the legal document that holds the government and contractor accountable for their responsibilities, the contract can play a significant role in cost, schedule, and other issues that arise. This paper investigates the consequences of the choice of contract vehicle. Is the structure of a contract affecting the ability of a program to receive its final products on time and on budget? Is DoD getting the bang for their buck? This paper utilizes the Contract Price and Schedule Database to inspect different types of contract price growth and where in the lifecycle of a program different contract vehicles and contract types may be contributing to unanticipated price growth.

Keywords

Data Collection, Data-Driven, DoD/MOD, Government, Contracts

Introduction

A contract is the legal document holding government and contractors accountable for their responsibilities and can play a significant role in cost and schedule issues on a program. This paper utilizes the Contract Price and Schedule Database – hereinafter "Contracts Database" or simply "KDB" – to investigate whether the selection of contract vehicles and contract types themselves contribute to these issues. It will also utilize historical contract price data to analyze different phases of the acquisition process and where contract vehicles/types play a larger role in contract price growth.

The Department of Defense (DoD) regularly procures more than any other US government agency, and in FY2017 more than all other agencies combined (Schwartz, Sargent Jr., & Mann, 2018). Agreeing on a contract with industry is an important part of this process, and can introduce significant risk on many levels. For example, choosing the wrong contract type can increase the cost to the government if the contractor does not deliver as planned. Issues arise depending on contract type, fee agreements for contractors, and contract vehicle. While any specific contract or program may only be a small part of the DoD budget, combined they significantly influence the non-discretionary portion of the federal budget and therefore taxpayer dollars.

Since 2004, the Air Force Cost Analysis Agency (AFCAA) has sponsored the management of the Contracts Database (KDB), a detailed collection of contract price and schedule data dating back to the 1990s. While other cost analysis agencies have contributed funding throughout the life of the project[1], AFCAA has been a constant for the past 15 years and along with Technomics has produced a large and reliable database. Analysts on the KDB project track detailed contract information such as contract vehicle type, contract type, phase, type of work, and growth category determination (see below) at the Contract Line Item Number (CLIN) and modification level. KDB is available to all government analysts in the Department via the Downloadable Tools page of the Data & Analytics section of the Cost Assessment Data Enterprise (CADE), accessible from https://cade.osd.mil/. This paper utilizes this information along with literature from the past decade to look into various characteristics of DoD contracts that may impact contract price growth.

Previous Research

KDB has proven to be a rich source of data for research questions, and we have only begun to scratch the surface. This paper builds on the work reported in two preceding papers in particular.

"Contract Geometry Best Practices for Incentive Contracting" (Braxton P. J., Hetrick, Webb, & Whitehead-Scanlon, 2017) focused on an initial exploration of the KDB data to determine whether cluster analysis could provide deeper insight into drivers of price growth. It made the compelling case that contract geometry for various contract types is a mathematical "filter" through which contract cost risk manifests, and it introduced the helpful distinction between this "on-the-shareline" risk and "off-the-shareline" risk, which sidesteps the contract geometry as part of a mod adding new work to the contract. This research identified the need to better understand and tag these types of historical cost growth in the database.

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[1] Naval Center for Cost Analysis (NCCA), Office of the Deputy Assistant Secretary of the Army for Cost and Economics (ODASA-CE), and Marine Corps Systems Command (MARCORSYSCOM) PEO Land Systems.

"Risk-Adjusted Contract Price Methodology (RCPM)" (Braxton, Hetrick, & Olbum, 2018) focused on describing the titular methodology for modeling both on- and off-the-shareline risk on new contracts. While this approach was certainly informed by KDB, we have not yet completed the data backfill effort necessary to break out cost and fee/profit where noted in the source contract documents. Until this is done, we will not have the quantitative data needed to fully analyze historical price growth related to contract type.

This paper draws attention to contract vehicle type and develops a clearer picture of risk profile by contract vehicle type, contract type, and phase. It re-introduces an innovative regression methodology to develop risk and uncertainty profiles to be applied to new contracts and summarizes the results of this methodology when applied to a representative subset of the KDB data.

KDB Growth Categories

An important aspect of KDB is the tracking of growth categories at the modification level. To explain, every modification added to the database is categorized relative to the underlying reason for the contract change as follows:

- **BASELINE**: Anticipated scope changes that affect the overall contract price, be it options exercised or procurement of items spelled out in the original Statement of Work
- **TECHNICAL**: Unanticipated scope changes that affect the overall contract price and scope, such as additional spares, storage, labor, etc.
- **COST**: Overall price changes that do not affect scope, such as cost overrun or underrun, or funding/obligation changes that affect contract price
- **SCHEDULE**: Schedule changes that directly impact the overall price changes
- **ADMINISTRATIVE**: Modifications which sum to zero dollars, no effect on overall contract price
- **FMS**: Any modification whose dollar plurality are for foreign military sales

In short, this set of growth category tags provides a comprehensive means of understanding price growth across the entire database.

Contract Vehicle Types

It is important to make a distinction between contract vehicle type (or simply "vehicle type") and contract type. While contract type describes type of payment agreement on a contract, the contract vehicle type, as specified by a single character in the contract number, describes the method of procurement on a contract. For example, a letter "D" in the contract number would indicate a contract type of Indefinite Delivery, Indefinite Quantity (IDIQ), commonly used when the exact number of items and the associated delivery schedule are not known to the government agency up front, and an initial contract is signed to allow for additional acquisition of the desired item from the contractor.

The main contract vehicle types this paper explores are C, D, and G. D, as stated above, refers to Indefinite Delivery, Indefinite Quantity (IDIQ) contracts, which consist of an initial master contract followed by any number of Delivery Orders (DOs) as the government agency determines what they need, when they need it, and how many they need of it from the contractor. This vehicle is frequently used when initial requirements are not well established. C contracts refer to the standard contract vehicle type (Federal Acquisition Regulation (FAR) Part 16, n.d.), generally used when initial requirements are more definite and there is a more established schedule. The government has already established what they want from the contractor, whereas in G contracts, Basic Ordering Agreements (BOAs), the government has the opportunity to be flexible in their needs from the contractor. The main difference between IDIQ contracts and BOAs is in competition. IDIQ meets requirements for competition at the time of initial award, but do not allow for participation by new contractors on additional delivery order awards. BOAs have no contractor limitations, and can efficiently "on-" and "off-ramp" contractors later on in the contract's lifetime. These vehicle types are similar in that they both are required to submit to an annual review (Capt. Daniel J. Finkenstadt & Timothy G. Hawkins, 2015). Table 1 shows the spread of contract vehicles present in KDB.

Table 1: Contract Vehicles in KDB

Contract Vehicle	Then Year Dollar (TY$) Value	% of Total
C - General	$ 452,154,789,347.89	80.2%
D - Indefinite Delivery, Indefinite Quantity (IDIQ)	$ 91,816,638,911.18	16.3%
G - Basic Ordering Agreement (BOA)	$ 18,515,437,330.58	3.3%
Other	$ 1,247,107,955.86	0.2%
Total	**$ 563,733,973,545.51**	**100%**

Table 2 shows that single-award vehicle types – the default C, plus the less common F, P, M, and K – represent the majority of the database (766 or 76.7%). The remainder are multiple-award vehicle types – D, G, and A, in decreasing order of precedence (233 or 23.3%). However, because the IDIQ (D type) vehicles average over 30 delivery orders (DOs) per contract, and BOA (G type) vehicles over 70, the DO-level counts swing strongly in favor of the multiple-award vehicles (9,213 or 92.3%).

Table 2 Vehicle Types Summary

Type	S/M	# Vehicles	# DOs	Avg. DO/Vehicle
A	multiple	1	15	15.00
C	single	656	656	1.00
D	multiple	180	5515	30.64
F	single	76	76	1.00
G	multiple	52	3683	70.83
K	single	1	1	1.00
M	single	4	4	1.00
P	single	29	29	1.00
		999	**9979**	**9.99**

Not only do IDIQ contracts make up a significant portion of the KDB, but they present plenty of risk when chosen or used incorrectly. While other agencies utilize IDIQ contracts, DoD accounted for 68% of IDIQ contract obligations between 2011 and 2015 (Government Accountability Office, 2017). The Government Accountability Office (GAO) found in a study that being able to issue separate orders rather than tack on modifications to one contract was more efficient for tracking movement on a contract. In other words, rather than lumping all actions on a product or service together, separate delivery orders are issued in IDIQ contracts for each additional piece of work. This would indicate that issuing D type contracts, or IDIQ contracts, could help prevent severe unanticipated cost growth.

While GAO found some level of efficiency with IDIQ contracts, a brief by Greg Garrett explores some additional characteristics of and potential pitfalls associated with IDIQ contracts. Garrett characterizes IDIQ contracts as allowing for increased competition initially, as well as later on for additional task orders (Garrett, 2013). While general (C) contracts involve competition up front for initial contract award, the multi-award nature of IDIQ contracts allow for further competition between contractors for subsequent delivery order awards. IDIQ contracts can be awarded to multiple contractors who can compete for delivery orders, resulting in an increase in competition for work. Additionally, for multiple-award IDIQ contracts, the prime contractor has an opportunity to capitalize upon significant profit/fee. One last concern is that while an IDIQ allows for additional future work that is somewhat “anticipated,” it is not guaranteed to be fully funded, nor does it guarantee that the actual work will come through.

KDB organizes contract vehicle types by contract number. A breakout by phase and contract vehicle is displayed in **Error! Reference source not found.**Figure 1. While G (BOA) contracts are absent during Production, they and D contracts make up a majority of O&S contracts.

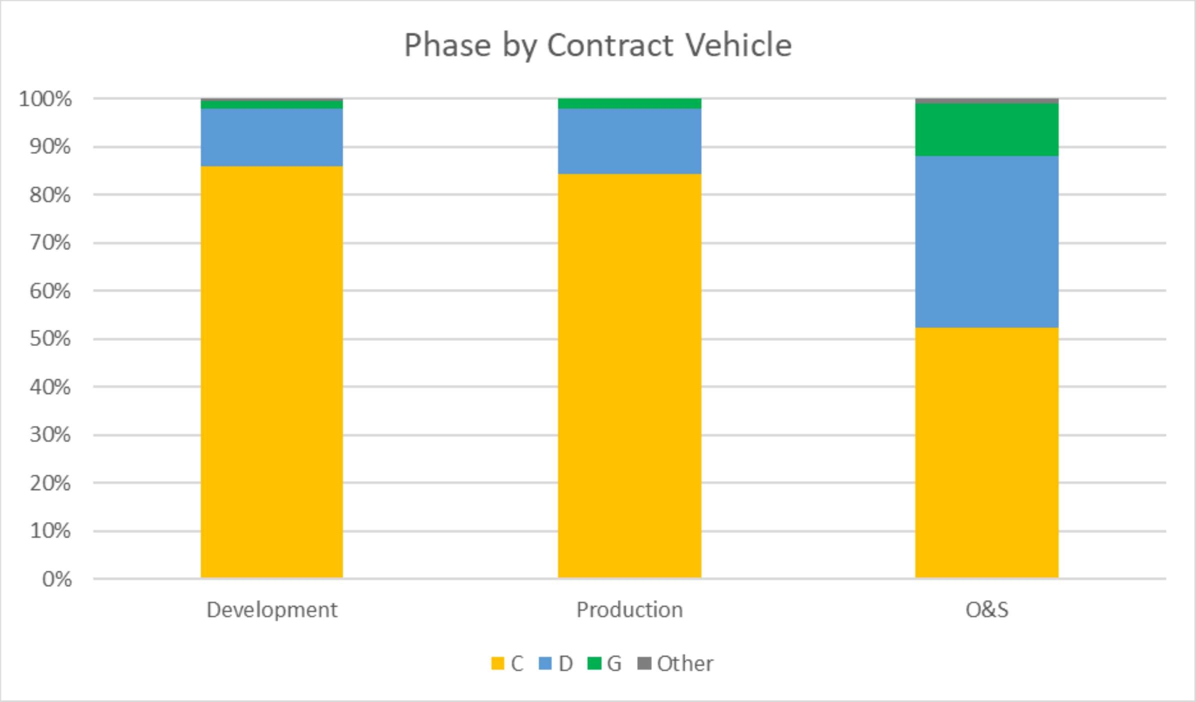

Figure 1: Phase by Contract Vehicle in KDB

Error! Reference source not found.Error! Reference source not found. shows that C type contracts are more frequent during Production, while D and G type contracts are more frequent during O&S. This graph is helpful to see where in the acquisition cycle each type is used, but the next three graphs will be more helpful to determine where unanticipated growth occurs on each vehicle. These graphs will show the breakout of growth categories by each vehicle type.

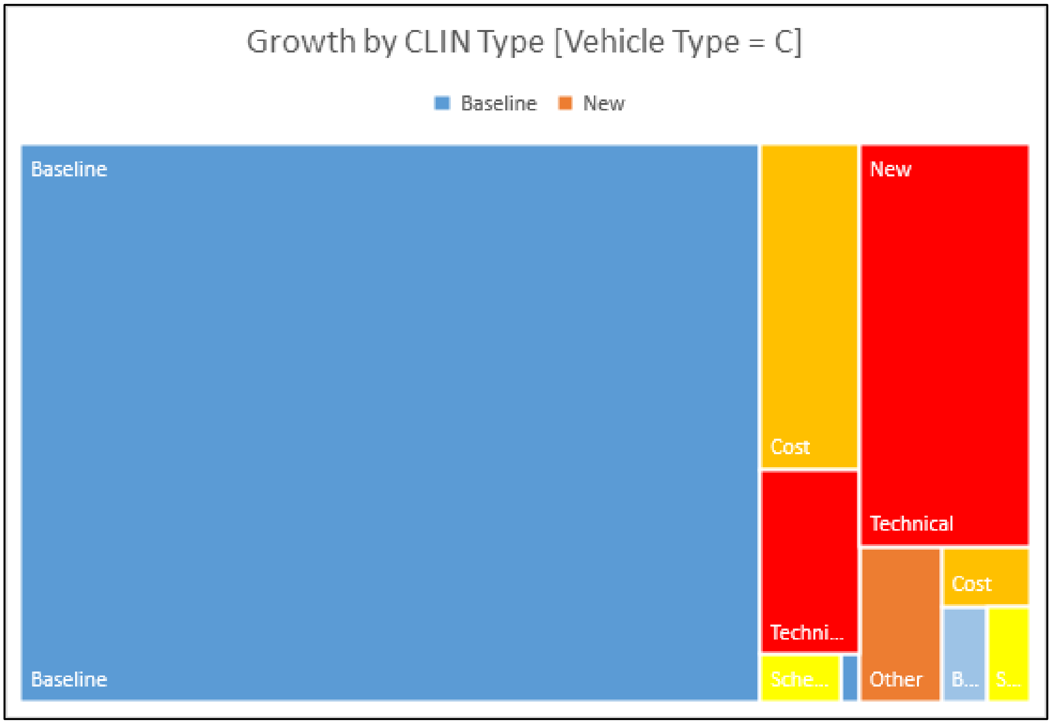

Figure 2: Growth by CLIN Type - C

Figure 2, Figure 3, and Figure 4 depict the growth categories by contract vehicle type for C, D and G type contracts, respectively.

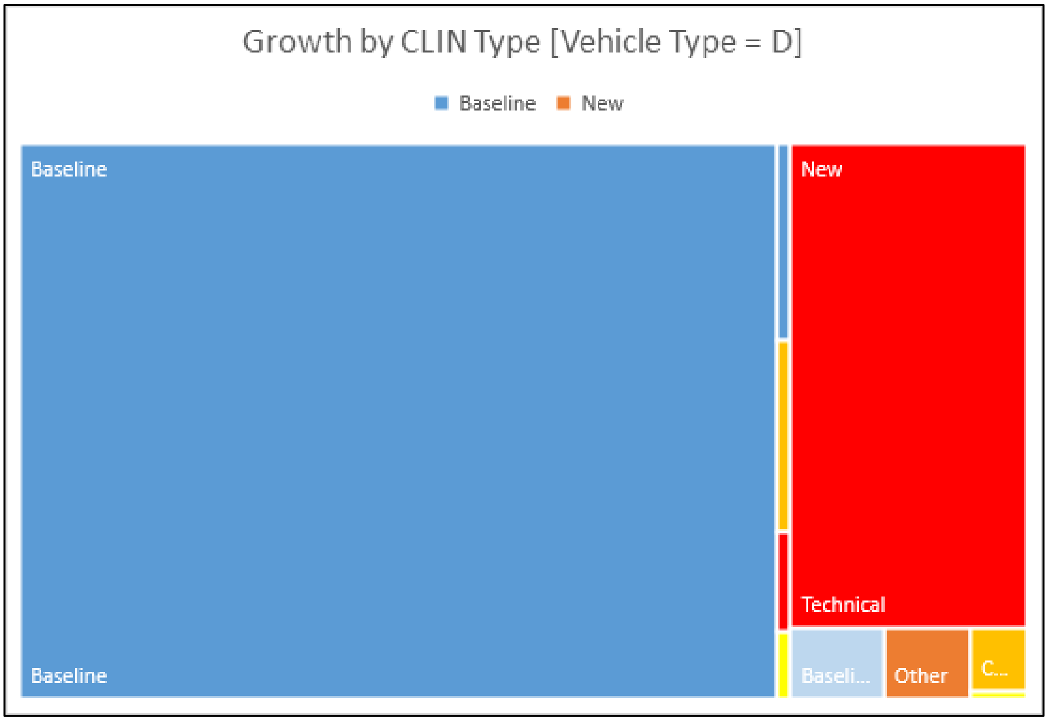

Figure 3: Growth by CLIN Type - D

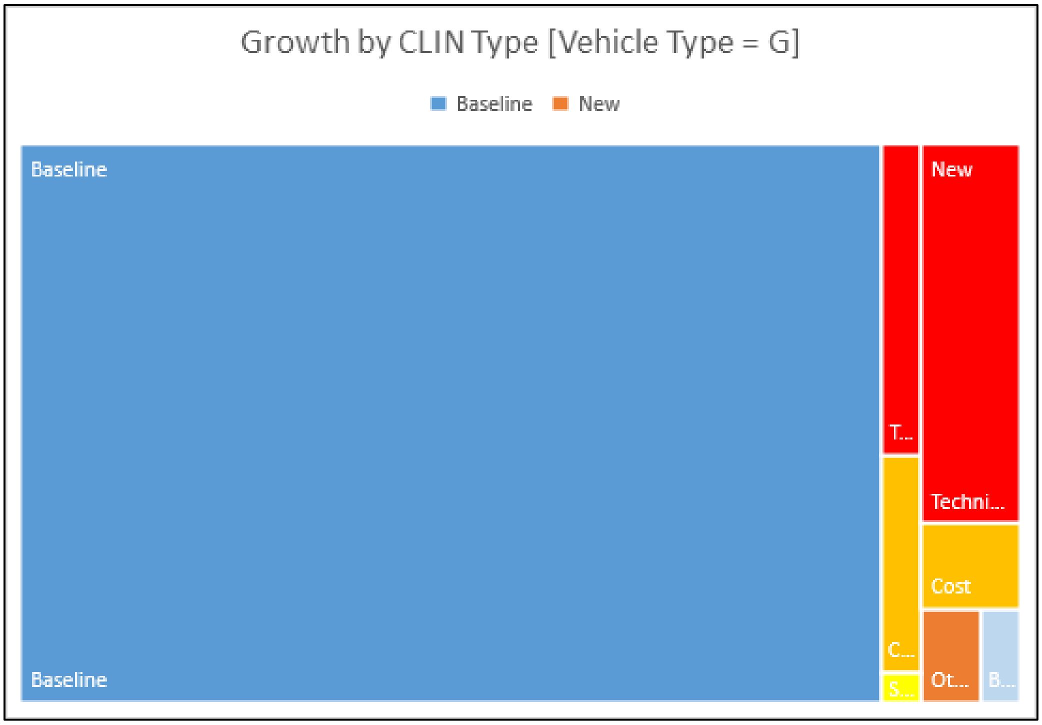

Figure 4: Growth by CLIN Type - G

The leftmost rectangle in each graph represents the total price of Baseline CLINs (i.e., those exercised or defined as options in the definitized contract). The next vertical "slice" is the growth on those CLINs, primarily in the Technical (red), Cost (orange), and Schedule (yellow) categories. The rightmost vertical slice represents New CLINs added to the contract after definitization and their subsequent growth in those same categories. We observe that for C-type contracts, addition of new CLINs account for about twice the price change as growth on Baseline CLINs. For IDIQ (D-type) contracts, there is almost no growth in the Baseline CLINs, but the addition of New CLINs accounts for almost enough to match the total growth of C-type contracts. BOAs (G-type contracts) seem to have less total growth, with growth concentrated in the addition of new CLINs, though not as severely as with D-type.

Contract Types

Contract types, defined at the CLIN level, determine fee and profit based on final cost (and possibly other contract performance criteria) for the contractor performing the work for the government. While some contract types incentivize manufacturers with a fee pool as a portion of the negotiated contract target price, other types promise only payment of the agreed amount, leaving some combination of the contractor and government liable for any difference between that price and final cost. Though we colloquially speak of "contract type" at the contract level, each CLIN has its own contract type, depending on the type of work, phase of acquisition, and other factors. The Contracts Database tracks contract type at the CLIN level, which allows us to compile the frequency of each type across phases, contract vehicle types, and growth categories.

Contract types are typically organized into three categories: fixed price, cost-reimbursement, and others that fit neither of those. In fixed price contracts, the contractor bears the risk, since the price is fixed, and the requirements are outlined early on. The government is required to pay the price of the contract, and cost and technical uncertainty remain low. In cost reimbursement type contracts, the government bears the risk, since the contract requires best efforts of the contractor for the duration of the contract rather than a set group of requirements. The contract price is typically an estimate at contract inception and solidified at the end of the contract. Technical and cost uncertainty are generally higher in cost-reimbursement type contracts. Table 3 shows the spread of contract types present in KDB by value and by percentage[2]. When grouped by Cost-Reimbursement, Fixed-Price, and Other, the table shows that Fixed-Price CLINs make up almost two thirds of the database.

Table 3: Contract Types in KDB

Contract Type	$TY Value	% of Total
FFP	$ 250,895,885,400.35	46.4%
FPIF	$ 82,217,665,963.91	15.2%
CPIF	$ 51,016,220,178.91	9.4%
CPAF	$ 88,453,238,794.47	16.4%
CPFF	$ 48,565,077,818.30	9.0%
Other	$ 19,526,886,199.07	3.6%
Total	**$ 540,674,974,355.01**	**100.0%**

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[2] The Total $TY in this chart does not match the other chart due to missing information in historical data.

More details on contract types may be found in the previously cited papers and in the Cost Estimating Body of Knowledge (CEBOK®) Module 14 Contract Pricing.

The Fixed-Price CLIN group comprises Firm Fixed Price (FFP), Fixed Price Incentive (FPI), Fixed Price-Award Fee (FPAF), and Fixed Price-Economic Price Adjustment (FPEPA). For certain contract types, a shareline (e.g., 70/30) is established, with the first number showing the percentage the government is responsible for and the second for the contractor.

Arguably the simplest contract type (Braxton, Hetrick, & Olbum, 2018), Firm Fixed-Price (FFP) is by far the most frequent contract type with 45% of the then-year dollars in the database (and an even higher percentage of CLINs by count). Risk on FFP contracts largely falls on the contractor, which accepts responsibility for any cost difference from the agreed upon price. Since the price is fixed, the contractor will see a higher profit for any cost underrun, and a lower profit for any cost overrun, leaving the government to pay the same price either way. Requirements on FFP contracts are largely fixed as well, and a memo from President Obama in 2009 stated that “Cost-reimbursement contracts shall be used only when circumstances do not allow the agency to define its requirements sufficiently to allow for a fixed-price type contract” (Deltek, Inc., 2012).

Another major fixed-price contract type, Fixed Price Incentive, allows for adjustments on profit for the contractor. Making up another large chunk of the database, FPI contracts are subject to a price ceiling negotiated before contract execution. The final price is determined based on the relationship between the final negotiated cost and the total target cost. Fixed price contracts in general are used for definite work such as follow-on production rather than for higher-risk contracts such as studies or research.

Cost-plus contracts are frequently used when quantity growth on the contract is a greater concern than cost growth. Cost-plus, or cost-reimbursement, type contracts pay the contractor a negotiated amount regardless of overrun. Cost Plus Fixed Fee (CPFF), another relatively simple contract type, presents a fee at a fixed dollar amount for the contractor. COST type CLINs, included in this row, are simply CPFF with zero fee (i.e., reimbursed at cost). Since the fee is fixed, any cost overrun or underrun causes an increase or decrease, respectively, in the overall contract price. Cost Plus Incentive Fee (CPIF) contracts define a minimum and maximum fee as a percentage of the target cost.

The “Other” category of contract types includes Fixed-Price Level of Effort (FPLOE) contracts as well as Time and Materials (T&M) contracts. T&M contracts shift the risk entirely from the contractor to the government, making it an unappealing contract type for contracting offices. These contracts allow services based on labor hours and material costs, and are used when an estimate of the actual work to be performed cannot be made.

There has been a recent emphasis on Incentive Contracting within the Department (Grady, 2016). Incentive-type contracts are primarily FPIF and CPIF, and the operation of the shareline on these two contract types is identical in the neighborhood of Target Cost. It is only when actual cost deviates significantly from the negotiated target that their behavior is substantively different. The stark difference in risk profiles for these two contract types shown below merits further investigation.

KDB provides a few interesting views. Keeping in mind that cost-reimbursement type contracts are of higher risk to the government, **Error! Reference source not found.** shows each contract type in KDB and relevance by life cycle phase. Fixed-price contracts are popular during Production, when there is higher certainty and less risk due to definite requirements laid out in the contract. Cost-Plus contracts prove to be more frequent in Development when requirements are not as concrete and changes are made more often on a contract. A 2017 GAO report looks into how to strengthen contracting practices and tighten methods in DoD. The report looks into obligation over time and risk attached to contract types, stating that cost-reimbursement type contracts are considered to be higher risk (Woods, 2017). The report states that "DoD guidance indicates that a cost-reimbursement contract is appropriate for research and development or for a major system prototype, while a fixed price incentive contract is suitable for the production of a major system based on the prototype or the long-term production of spare parts for a major system." KDB reflects these facts, with over half of cost-reimbursement contract dollars in Development and the majority of Fixed-Price contract dollars in Production.

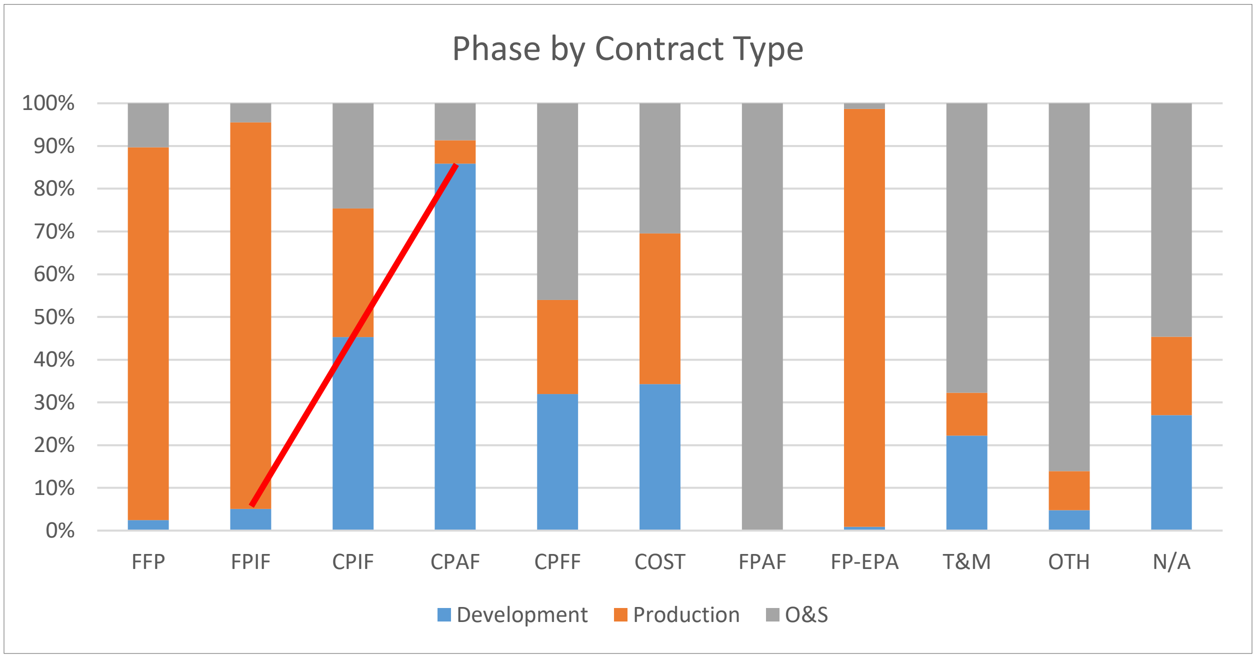
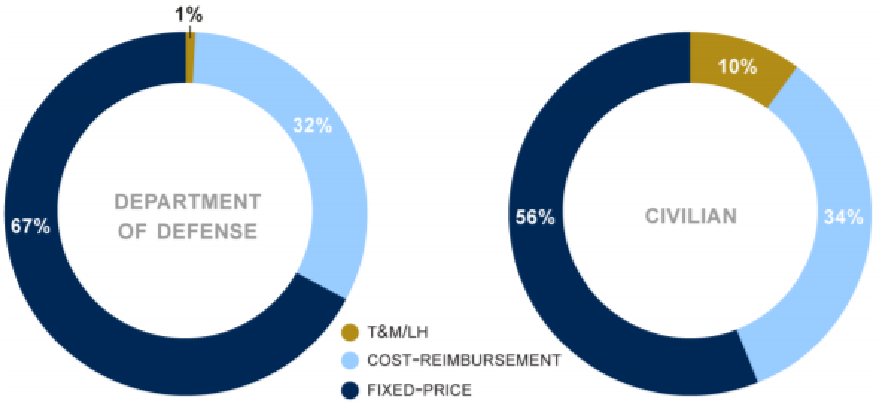


Figure 5: Phase by Contract Type in KDB

Additionally, the GAO report displays obligation by contract type, shown below.



T&M/LH = Time and materials/labor hours

Source: GAO analysis of Federal Procurement Data System – Next Generation data. | GAO-17-244SP

Figure 6: GAO DoD Contract Type Breakout

KDB reaffirms what the report says for DoD: Fixed-Price contracts make up about two-thirds of DoD spending, as shown in Figure 8.

Another graph (**Error! Reference source not found.**) shows that KDB reflects the definitions of Fixed-Price and Cost-Plus contracts: unanticipated (i.e., technical) growth is higher on Cost-Plus contracts used when requirements aren't known or aren't set in stone than Fixed-Price contracts. The graph below shows contract types broken out by the most common growth categories Baseline, Technical, and Cost.

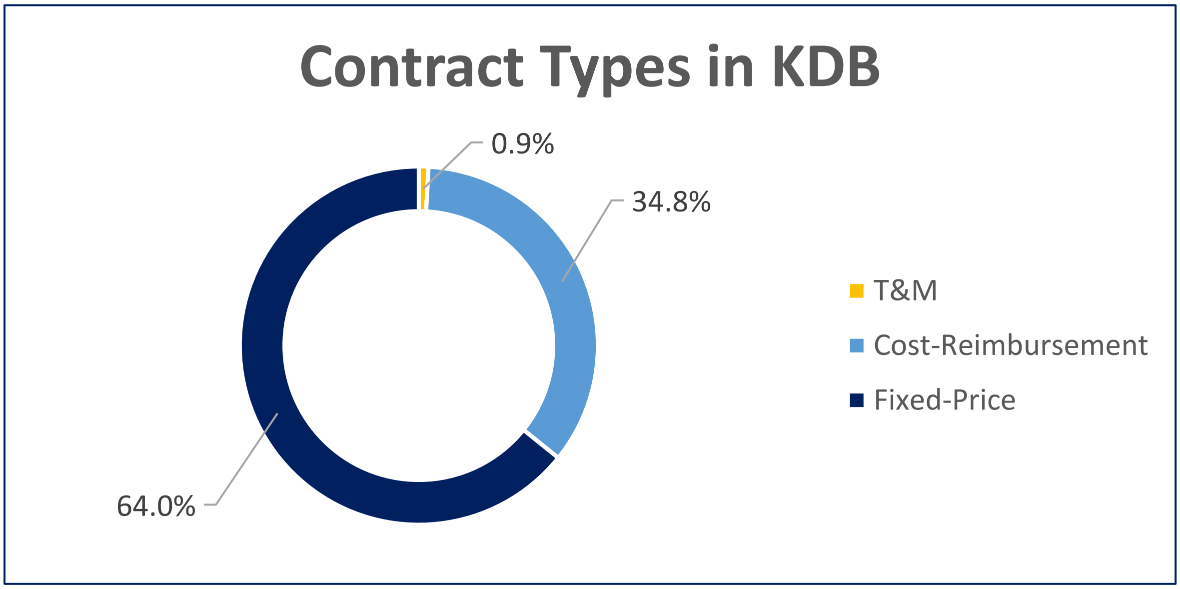


Figure 7: Contract Types in KDB

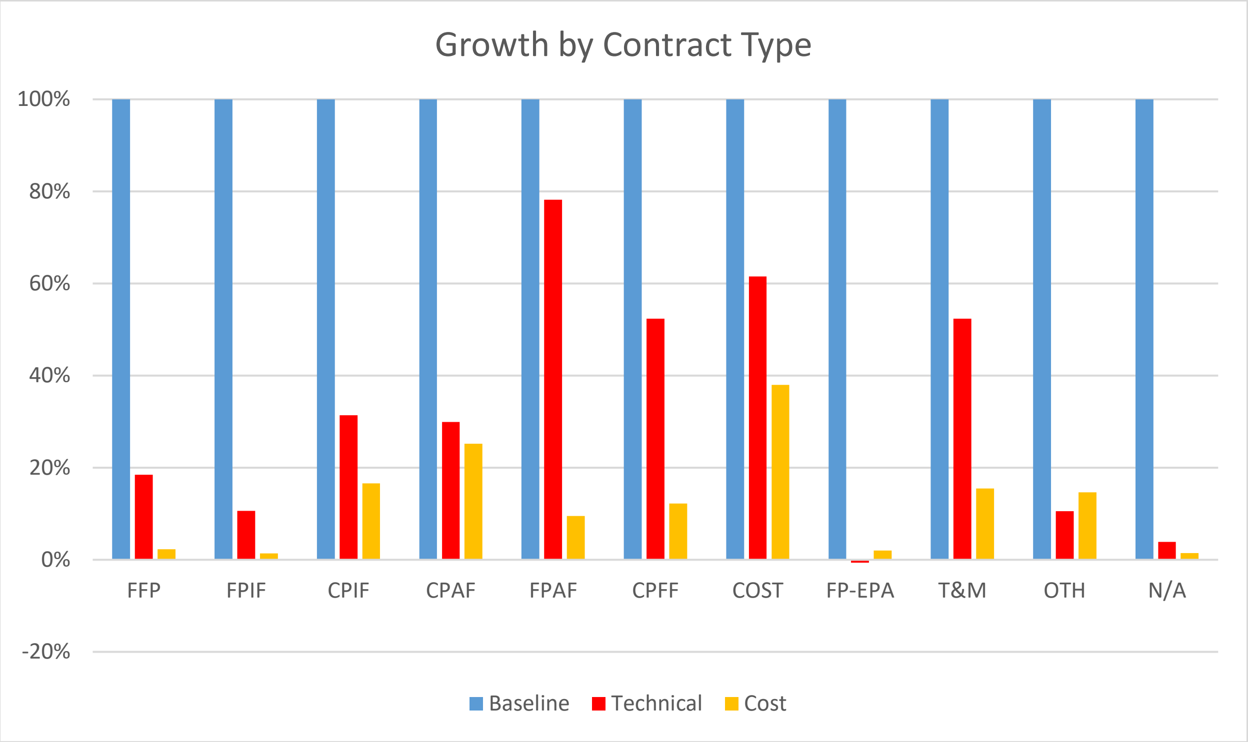


Figure 8: Growth by Contract Type in KDB

As expected, Fixed-Price contracts have a higher Baseline, or anticipated, percentage of total contract price. Cost and Cost-Plus contracts have higher Technical growth, as do T&M contracts that are frequently employed for Operations & Support (O&S) contracts.[3]

From Aggregate to Estimate-Level Risk

The preceding discussion and summary statistics show aggregate historical growth across the database by vehicle type, contract type, and life cycle phase. However, since not all contracts, DOs, or CLINs are created equal, we devised a parametric methodology that allows us to leverage the entirety of a proper subset of the data in applying risk and uncertainty to a new estimate. This section describes this methodology, which represents a significant improvement to the traditional factor approach.

Maximum Likelihood Estimation (MLE) Regression

This risk approach was pioneered in the "Perils of Portability" paper (Braxton, et al., 2011). As there, the implicit driver is size (in this case, baseline contract price, as opposed to total program cost). This method has two primary advantages over a simple factor: (1) allows for economies or diseconomies of scale; and (2) includes an uncertainty distribution, which itself scales with size. The hypothesized relationship is that larger contracts have larger uncertainties in absolute dollar value terms (i.e., standard deviation) but smaller uncertainties in relative percent terms (i.e., CV). This is the well-

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[3] The FP-EPA calculates negative Technical growth and does not equal 100% due to Administrative modifications having value. Though a modification with no dollar delta is Administrative, realignment of money between CLINs can cause an increase or decrease in the contract type splits, thus not calculating to 100% in the graph above.

documented "Size Effect." (The Joint Strike Fighter (JSF) program continues to raise consternation as a counterexample, with mind-bogglingly large cost growth in both absolute and percentage terms!)

To better elucidate the MLE Regression approach, let us build it out as a generalization of simpler regression models. If we start with the "pure factor" model and allow uncertainty but not a non-zero y-intercept, we have:

$$Y_i = \beta_1 X_i + \varepsilon_i$$

Allowing a non-zero y-intercept and making the traditional assumption of unbiased homoscedastic error, we have the single-variable Ordinary Least Squares (OLS) regression model:

$$Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i, \varepsilon_i \sim N(0, \sigma^2)$$

In order to account for the Size Effect while retaining an additive Normal error term, we must allow the variance to scale with size as indicated by the Baseline x-value. While several formulations are possible, previous research found a linear formulation with non-zero y-intercept to be the most suitable. This allows for a variance that doesn't vanish for small values of the independent variable ($\alpha_0 > 0$), and it also results in a standard deviation that increases at a decreasing rate (since variance increases at a linear rate but standard deviation is the square root of variance). Roughly speaking, this results in a "fish head" shape on the scatterplot, instead of a strictly linear "cone of uncertainty."

$$Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i, \varepsilon_i \sim N(0, \alpha_0 + \alpha_1 X_i)$$

We can then see from the right-hand side of the equation that the dependent variable can be seen as a Normal random variate, where both mean and variance are linear functions of the independent variable:

$$Y_i \sim N(\beta_0 + \beta_1 X_i, \alpha_0 + \alpha_1 X_i)$$

If we take the probability density function (pdf) of this Normal as the likelihood of each y-value, then the overall likelihood function is the product of these,

$$L = \prod_{i=1}^{n} \frac{1}{\sqrt{2\pi\sigma_i^2}} exp\left(-\frac{(Y_i - \mu_i)^2}{2\sigma_i^2}\right) \quad , \mu_i = \beta_0 + \beta_1 X_i, \sigma_i^2 = \alpha_0 + \alpha_1 X_i$$

and the log likelihood turns that product into a sum

$$\log L = \sum_{i=1}^{n} \left[\log \frac{1}{\sqrt{2\pi\sigma_i^2}} - \frac{(Y_i - \mu_i)^2}{2\sigma_i^2}\right] = -\frac{1}{2} \sum_{i=1}^{n} \left[\log(2\pi\sigma_i^2) + \frac{(Y_i - \mu_i)^2}{\sigma_i^2}\right]$$

Since we are trying to *maximize* the likelihood function (and hence the log likelihood function), we can equivalently *minimize* the opposite of the log likelihood function and get rid of all those pesky leading negatives:

$$-\log L(\beta_0; \beta_1; \alpha_0; \alpha_1) = \frac{1}{2} \sum_{i=1}^{n} \left[\log(2\pi\sigma_i^2) + \frac{(Y_i - \mu_i)^2}{\sigma_i^2}\right]$$

We have also included the four parameters parenthetically to emphasize that the optimization is as a function of those four input values. (This is a typical "standing on your head" regression thought process. Instead of the typical orientation where the parameters are constants and the variables are unknowns, now we have the variables as constants – historical data for Initial and Final values – but the parameters as unknowns, with the flexibility to achieve the desired "best fit.") Finally, we can ignore multiplicative and additive constants to simplify the expression whose value we need to minimize:

$$\min_{\beta_0;\beta_1;\alpha_0;\alpha_1} \sum_{i=1}^{n} \left[\log\left(\sigma_i^2\right) + \frac{(Y_i - \mu_i)^2}{\sigma_i^2}\right], \mu_i = \beta_0 + \beta_1 X_i, \sigma_i^2 = \alpha_0 + \alpha_1 X_i$$

While intuition will only take us so far in cases like this, a basic sanity check is in order. The beta parameters give us the flexibility to get the regression line as close to the data points as possible, measured vertically as a sum of squares of differences between the observed and predicted y-values. This is similar to the sum squared error (SSE) from OLS regression, except it is now scaled relative to the heteroscedastic variance. As this variance grows without bound, the SSE-like second term vanishes, but this is counterbalanced by the first term, which grows with the variance. Roughly, we want to the variance to grow enough to accommodate data points farther from the regression line but not too much, which would lead to cross-sectional normal distributions too flat and dispersed, with *any* likelihood extremely low.

Before running our optimization, we need to discuss general *a priori* expectations for the values of the four parameters. α_0 needs to be strictly positive, because we must always have a positive variance. Moreover, variance should be monotonically non-decreasing with size, so that α_1 should be non-negative. We expect β_0 to be relatively small in magnitude – it would be zero for a pure factor – but we're not particularly worried about negative values, so we'll leave it unconstrained, at least initially. Finally, we expect $\beta_1 > 1$ (net growth), but as long as that coefficient is strictly positive, we should be OK. Generally, an initial value of 1.2 (20% growth) would be reasonable.

By definition, x-values are positive, since they represent a non-zero amount of BASELINE work. Similarly, y-values are nonnegative, since we can never have lower than -100% growth! Negative data values are not a concern for the numerator of the second term in any case, since we are squaring the difference. The concern with negative values would be if a negative x-value combined with the constrained alpha values to produce a negative variance. That would be doubly problematic, since it would cause both (1) an undefined logarithm in the first term, and (2) a reversal of the sign (and hence optimization) of the second term.

As with any optimization, we are concerned that the method applied may yield a local minimum and not a global minimum, but with a reasonable set of initial values, some trial and error, and sanity checking the results, we feel reasonably comfortable.

A further improvement would be the same methodology with some sort of risk score as an alternate driver.

Technical and Total Growth Benchmarks

The primary application of the MLE Regression methodology is to model growth of the Baseline CLINs. In this case, the "denominator" is the sum total of Baseline prices of BASIC and Option CLINs. The "numerator" is either Total growth, represented by the middle vertical slice in the tree maps above (e.g., Figure 2), or Technical growth, the red portion of that middle vertical slice.

As an example, the MLE Regression for Technical growth on Firm Fixed Price (FFP) contracts – or more properly the aggregation of all FFP CLINs on those contracts with FFP CLINs – is shown in Figure 9. The graph on the right is simply the zoom in to the green box on the graph on the left so as to better show the majority of the data points. The solid green line is the MLE Regression, and the two dashed green lines represent plus or minus one standard deviation of the heteroskedastic normal error term. (Note that the blue line and corresponding equation are *not* the MLE Regression, but rather the tradition OLS regression, included for comparison purposes only.)

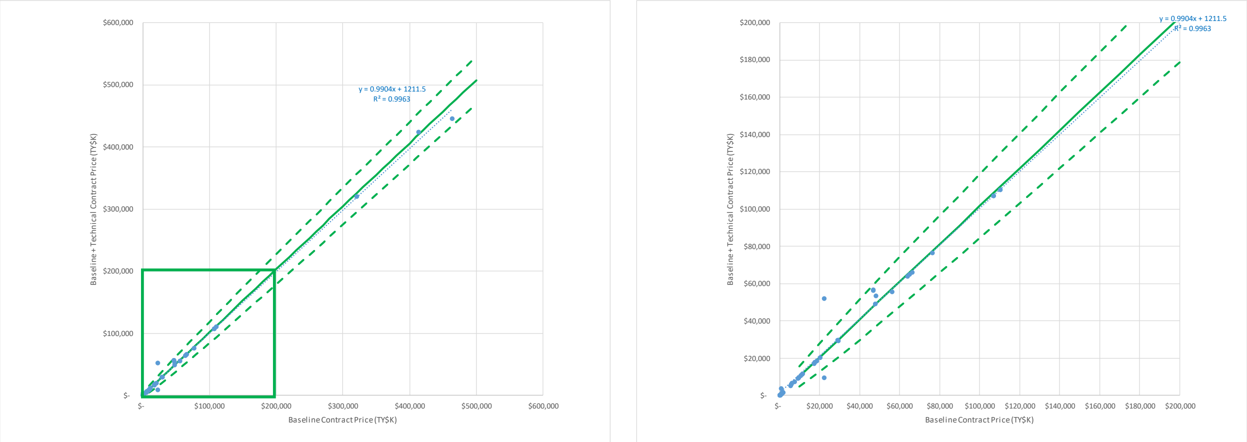

Figure 9 MLE Regression Example (with Zoom)

It is also possible to show the "CGF View" of these graphs (see Figure 10). Instead of final price vs. baseline price as before, we now divide by the latter so as to show a cost growth factor (CGF). Whereas before we compared to the "perfect" 45-degree line ($Y = X$), we now compare to the horizontal line $CGF = 1.0$. The dashed lines, instead of illustrating a widening error in absolute dollar terms, now illustrate the narrowing error in relative terms of the coefficient of variation (CV).

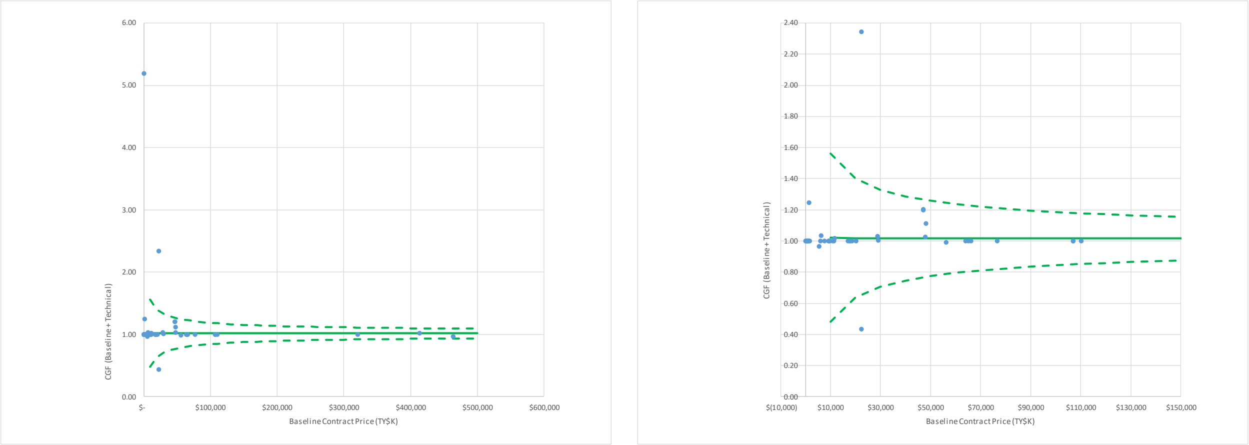

Figure 10 MLE Regression Example (CGF View)

A sleek MLE Regression template was designed in Microsoft Excel, using the native Solver Add-in to run the requisite optimization. This template automatically generates the four graphs shown, though some fiddling with scale of the axes is often required. It will increase the efficiency and fidelity of MLE Regressions produced by analysts in the future.

Technical Growth Benchmarks

A summary of the resulting Technical Growth benchmarks is shown in Table 4. Both of these summaries represent C-type contract vehicles and Development contracts. The FPIF contract type is relatively rare, as would be expected for Development, but it shows even lower risk than FFP.

Table 4: Technical Growth Benchmarks

Data set	KDB (all)
Vehicle Type	C
Aggregation	Contract CLINs, grouped by Contract Type
Risk	growth on Baseline CLINs
Decomposition	Technical growth

	TY$K	**$ 10,000**	**$ 50,000**	**$ 100,000**	**$ 500,000**
CPFF / COST	**Growth**	14.07%	6.92%	6.03%	5.32%
	CV	133.17%	63.54%	45.31%	20.40%
	n	50	22	9	3
CPIF	**Growth**	63.97%	46.18%	43.96%	42.18%
	CV	432.80%	215.87%	154.89%	70.09%
	n	10	9	16	7
FPIF	**Growth**	-0.63%	0.11%	0.20%	0.27%
	CV	5.05%	2.24%	1.59%	0.71%
	n	1	1	4	4
FFP	**Growth**	2.33%	1.67%	1.59%	1.52%
	CV	52.85%	23.79%	16.84%	7.53%
	n	34	11	3	3

Total Growth Benchmarks

A summary of Total Growth benchmarks is shown in Table 5. The third row in each grouping shows the number of data points (n) in each size “bucket.” The table illustrates the size effect, wherein both growth and CV percentages decrease with size. In some cases, this is gradual; in others, quite dramatic. The lower growth percentages and CVs for fixed-price contract types (as compared to cost-plus) accords with conventional wisdom. However, the extremely high values for Cost Plus Incentive Fee (CPIF) are surprising. Upon inspection, the regression results are heavily influenced by three high-value high-growth data points. These merit further research.

Table 5: Total Growth Benchmarks

Data set	KDB (all)
Vehicle Type	C
Aggregation	Contract CLINs, grouped by Contract Type
Risk	growth on Baseline CLINs
Decomposition	Total growth

	TY$K	**$ 10,000**	**$ 50,000**	**$ 100,000**	**$ 500,000**
CPFF / COST	**Growth**	27.90%	13.86%	12.11%	10.71%
	CV	198.68%	99.46%	71.40%	32.33%
	n	50	22	9	3
CPIF	**Growth**	110.85%	90.48%	87.93%	85.89%
	CV	532.32%	262.36%	187.93%	84.93%
	n	10	9	16	7
FPIF	**Growth**	2.45%	1.86%	1.78%	1.72%
	CV	30.14%	13.56%	9.59%	4.29%
	n	1	1	4	4
FFP	**Growth**	0.54%	-0.09%	-0.17%	-0.23%
	CV	62.46%	28.11%	19.89%	8.90%
	n	34	11	3	3

Closing Thoughts

All in all, the methods used by DoD in contracting are impacting how much is being spent. Some of the decisions made in contracting happen early in the life of a contract, such as whether or not to change manufacturing techniques during Development or adjust the number of items procured during Production. Some risk can be pinpointed at the beginning of the contract, such as deciding on an appropriate contract vehicle and contract type.

Decisions on contract vehicle and contract type alike are determined by a number of things, such as how specific the requirements of the program are, where in the acquisition cycle the program is, and historical performance by the contractor in question. The Contracts Database shows that C type contracts are more frequent during Production, while D and G type contracts are more frequent during O&S. This aligns with literature; general contracts require well-defined requirements, as typical of Production specifications, while O&S may call for the increased flexibility of IDIQ contracts to provide spares, repairs, and other support on an as-needed basis.

Contract types get a bit trickier. Since they are defined at the CLIN level, contract types aren't always fully determined at the beginning of a contract. Fixed-price contracts are widely used during Production, when there is higher certainty and less risk due to definite requirements laid out in the contract. Risk is on the contractor to deliver exactly what was arranged initially. Cost-Plus contracts prove to be more frequent in Development when requirements are not as concrete and changes are made more often on a contract. Risk lies with the government to maintain a design and manufacturing schedule, among other responsibilities.

This paper provides two sets of key results. First, the tree maps vividly illustrate substantively different patterns of growth – split between growth on Baseline CLINs and addition of New CLINs – across the primary C, D, and G contract vehicle types. Second, the MLE Regression methodology bridges the gap between this aggregate historical cost growth and specific contract risk, providing a high-fidelity estimate of risk and uncertainty to be applied when estimating new programs and contracts. This approach can be applied to any data set comprising Initial (baseline, target, or estimate) and Final (actual) values. In this case, we have excerpted data sets from KDB, filtering by vehicle type (e.g., C) and phase (e.g., Development), and grouping CLINs of a common contract type.

While it is comforting that these historical data align with literature and conventional wisdom, the challenge remains to save taxpayer money and further assist the government in maintaining best practices in contracting. A clearer understanding of risk by vehicle type and contract type, and guidelines for what types are appropriate for a given lifecycle phase and scope of work, enable us to do so.

Path Forward/Future Work

We are digging deeper into the root causes of cost and schedule growth on contracts. This paper embodies a top-down parametric approach. We have provided views of aggregate cost growth by vehicle type, contract type, and phase, and presented a systematic and statistically robust approach to using *all* the data within an appropriate subset of KDB to model risk and uncertainty on new contracts. Over the next several months, we will be taking more of a bottom-up analogy approach by conducting “deep dives” on a number of Air Force aircraft programs, comprising both new and modernization efforts. The goal will be to better parse out historical cost growth and align it with cost estimating use cases to determine whether that growth would’ve been included in the base estimate, depending on whether technical and schedule risk assessments were conducted. A broader program context, including the acquisition strategy, competitive landscape, and sequence of contracts, will also prove informative.

We also need to better understand contract growth via New CLINs (the rightmost vertical “slice” of the tree maps). Does this really represent new, unanticipated work, or are there cases where a new CLIN is more accurately seen as growth to an existing CLIN? Does this necessitate a new kind of tagging in the database, or can it be handled adequately on a case-by-case basis? This leads us to consider the fractal nature of risk. By default, KDB assumes that each distinct contract and DO represents its own (Baseline) scope of work, but there likewise may be cases where they more properly represent unanticipated growth on another contract or DO. The deep dives should provide insight into these questions and issues.

We still believe the notion of appropriateness of contract type for a given situation is very important. To some extent, this may require expertise on individual programs, but if we can tag CLINs with more precise phases – Technology Maturation and Risk Reduction (TMRR), Engineering and Manufacturing

Development (EMD), and various Low-Rate Initial Production (LRIP) and Full-Rate Production (FRP) lots – and scopes of work, we should be able to assign some sort of appropriateness rating based on conventional wisdom and rules of thumb. Phase determination can become tricky, as platforms (e.g., the C-5 Galaxy) may be well into the O&S phase when an associated modernization effort essentially becomes its own program (e.g., Reliability Enhancement and Re-engineering Program (RERP)), with its own Development and Production phases and contracts.

To date, we have relied on the Schedule growth category to capture contract price growth attributed to schedule slips, but KDB contains a wealth of schedule data by CLIN in the form of mod dates (when each CLIN was definitized, exercised, and modified) and Period of Performance (PoP) delivery dates. Examining how the latter change over time, as tracked by the former, would inform not only schedule growth itself but the aforementioned cost growth due to schedule.

This is but a sampling of potential uses of KDB in cost research and applied estimating. We urge readers to consider possible applications in their areas of interest and shared their ideas with the authors.

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