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Avoiding Terminations, Single Offer Competition, and Costly Change Orders With Fixed-Price Contracts

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Avoiding Terminations, Single Offer Competition, and Costly Change Orders with Fixed-Price Contracts[1]

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Abstract

Fixed-price contracts offer the promise of controlling costs but are less likely to succeed when there is uncertainty regarding requirements. While these broad principles are uncontroversial, disagreement rages regarding the practical question of how widely they should be used. This study tests a variety of hypotheses regarding what contract characteristics are associated with better performance under fixed-price contracts. Here, performance is measured across three dependent variables: (a) the Number of Offers Received for competed contracts, (b) whether the contract was terminated, and (c) the extent to which change-orders raised the contracts' cost ceiling. The study team has created a Bayesian network, populated by completed, publicly reported DoD contracts from FY2007 to FY2013 to address this research question.

The public purpose of this process also includes facilitating future acquisition research on a range of topics. To support future research, all analytical data and codes developed and/or used are posted on the CSISdefense GitHub (Sanders, 2015). This resource addresses two vexing issues that bedevil a wider use of the Federal Procurement Data System (FPDS) by academia, government, and industry researchers, namely (a) the data-selection barrier to using the FPDS and (b) the difficulty of deriving performance outputs from FPDS.

[1] The Center for Strategic and International Studies (CSIS) does not take specific policy positions; accordingly, all views expressed in this presentation should be understood to be solely those of the author(s).

Introduction

The current preference within the executive branch and congressional oversight committees for fixed-price contracts is a reaction to external budget pressures and cost overruns associated with certain high profile acquisition programs (Younnossi et al., 2007).[2] But even the DoD acknowledges that fixed-price contracting is not a panacea for all that ails federal acquisition.[3] Discussions on the role of fixed-price contracting in acquisition is really a discourse on requirements, risk allocation, and uncertainty. Accordingly, as a contracting vehicle, fixed-price contracting will find more utility in specific, well defined scenarios such as in events where requirements and likely costs are well understood. More so, than in contracting situations characterized by uncertainty. This issue is acknowledged by OMB which has issued the guidance governing such acquisition transactions (Office of Management and Budget, 2009).

Under what circumstances are fixed-price contracts most likely to succeed?[4] This paper addresses that question by examining seven years of DoD contract transactions available through the Federal Procurement Data System (FPDS). The project compares the performance results of fixed-price and cost-based contracts across a range of characteristics that typically would be known to the contracting officer before the contract was signed. While FPDS does not directly measure performance, it does capture three variables that directly measure the possible drawbacks of fixed-price contracts. These are

- Single Offer Competition,
- Contract Terminations, and
- Cost-Ceiling-Raising Change Orders.

"Single-Offer Competition" can be indicative that the pricing vehicle involves too much risk on the vendor side, which makes bidding on the contract unattractive to potential vendors. Tracking "Contract Terminations" addresses the risk of outright failure because a

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[2] Cost growth in defense acquisition is driven by several factors that include schedule, unrealistic estimates, acquisition strategies and funding availability. Studies of weapon system cost growth, notably by researchers indicate that across board the average adjusted total cost growth for a completed program was 46% over the study period of 30 years.

[3] On numerous occasions, Frank Kendall, the under secretary of defense for Acquisition, Technology, and Logistics, has underscored the need to use appropriate contracting vehicles by pointing out the problems that a fixed-price contract caused during its development of the A-12 Avenger.

[4] The concept "fixed price" deserves some further illustration. A fixed-price contract suggests a price that is not subject to any adjustment on the basis of the contractor's cost experience in performing the contract. And according to provisions in the Federal Acquisition Regulation (FAR), a firm-fixed-price contract is suitable for acquiring commercial items (see Parts 2 and 12) or for acquiring other supplies or services on the basis of reasonably definite functional or detailed specifications (see Part 11) when the contracting officer can establish fair and reasonable prices at the outset. But as is succinctly noted in the DoD's (2014) *Performance of the Defense Acquisition System: 2014 Annual Report* (pp. iii–vi), "Prices on fixed-price contracts are only 'fixed' if the contractual work content and deliverables remain fixed"; such contracts can be (and often are) easily modified to handle unexpected technology gaps, engineering issues, or shifting threats, leading to cost growth. At times fixed-price vehicles can be virtually indistinguishable from cost plus vehicles, as was the case with the Air Force's canceled Expeditionary Combat Support System (ECSS). This reading of "fixed price contract" by the DoD guides our understanding of fixed-price contracts in the framework of this study.

vendor has taken on more risk than they can handle. And finally, "Cost-Ceiling-Raising Change Orders" demonstrates that the government customer finds the present contract structure unsatisfactory and may indicate cost overruns.

The study team analyzes the drivers of these three dependent variables using a Bayesian network populated with all unclassified[5] completed DoD contracts from FY2007 to FY2013. The study objective is to determine when fixed-price contracts are most effective. The team drew hypotheses from the literature regarding under what circumstances the fixed-price mechanism would lead to better results. The team also developed control variables. These controls divide the data to capture factors not relating to pricing mechanism that may lead to better or worse performance.

Addressing the question of when fixed-price contracts are most effective is only a portion of the public purpose of this project. The data that undergird this investigation originate from FPDS and are thus open source and pertinent to a wide range of government contracting questions. With this chosen approach, the study team simultaneously addresses two of the most vexing issues that have bedeviled the wider and more effective use of FPDS by academic, government, and industry researchers: the high barrier to entry for accessing complete and relevant data and the difficulty of deriving performance outputs from FPDS.[6] To ensure reproducibility of this analysis and to provide a starting point for future research, the entirety of the dataset is published through the CSISdefense GitHub account along with the typographies and analytical code that the study team used to create the statistical models (Sanders, 2015).

Background

Since the inception of the federal acquisition business, issues of performance have vexed policy-makers. In the last years, major data analytics work by DoD analysts found scant statistical correlation between industry profit margins and program performance in cost and schedule. For example, rigorous analysis of data from hundreds of major weapons programs strongly suggest that hitherto fixed-price contracting does not always achieve the set goals (DoD, 2014). As far back as 1949, John Perry Miller, in *Pricing of Military Procurements*, exposed the lack of symmetry between incentives and contract performance (as cited in Williamson, 1967, p. 218). In the same hue, scholarly works from the early 1960s by Frederick M. Scherer (1964) and Peck also support the notion that there is a discrepancy between values attached to incentives and performance results (Kaysen, 1963). Speaking to this issue, Williamson (1967) glumly stated,

> My analysis of these relations leads me to conclude that neither the manipulation of profit incentives, nor the monitoring of contract progress can be expected, in any dependable sense, to yield significant improvements in contract performance as long as the specification of the task remains unchanged. (pp. 217–218)

Procurement has long been at the top of the government's laundry list of activities that need improvement. However, this policy focus has come in cycles—with attendant ups

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[5] There is no regulatory mandate to report classified contracts; as a result, CSIS assumes that they are not included within FPDS.
[6] For a more detailed remark on these factors, please see the following section of this report.

and downs over the years. Practically every administration since the 1970s has embarked on some form of acquisition reform or at least paid lip-service to the process. Over 150 major studies devoted to the field of acquisition reform have been produced since the end of the Second World War (Schwartz, 2014). Despite these efforts, according to Congressional Research Service analyst Moshe Schwartz, DoD development contracts since 1993 have experienced a median of 32% cost growth—not adjusted for inflation. Since 1997, 31% of major defense acquisition programs have had cost growth of at least 15%. Schwartz observed that every year between 1996 and 2010, the Army spent more than $1 billion on programs that were ultimately canceled.

In 2009 and 2010, these problems led to the latest round of reforms, including the Weapon System Acquisition Reform Act and Better Buying Power. The first set of DoD Better Buying Power initiatives called for greater use of fixed-price incentive fee contracts when appropriate (Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics [OUSD(AT&L)], 2010). The second iteration of these reforms in 2012 suggested fixed price for low-rate initial production but emphasized contracting officer discretion in choosing the right pricing mechanism (OUSD[AT&L], 2012). In 2013, the annual report on the *Performance of the Defense Acquisition System* reinforced this change, finding that use of fixed-price contract types were not themselves correlated with cost savings. Throughout this debate, all sides agree that fixed-price contracts are more appropriate in some cases than in others.

Study Dataset and Performance Measures

The dataset for this study consists of DoD contracts reported in FPDS that were initially signed no earlier than FY2007 and completed by FY2013. Notable exclusions include classified contracts not mandated to be reported in FPDS, contracts funded but not managed by the DoD, and Defense Commissary Agency contracts which have not been reported in recent years.[7] To enable comparisons, the dataset is not limited to fixed-price contracts.

Determining when contracts are completed is the most challenging portion of compiling the dataset. Contracts closed out or terminated by the end of FY2013 are included even if their current completion dates run into the next fiscal year. However, many contracts in FPDS and in the sample are never marked as closed out or terminated in the *Reason for Modification* field. In these cases, completion status is based on the current completion date of the most recent transaction in FPDS. This method could accidentally include contracts that have not reached their ultimate conclusion dates and are merely dormant. However, the FY2013 sample end date means that any such contracts would have to be inactive for an entire fiscal year, which is remarkably unlikely.

FPDS raw data is available in bulk from USAspending.gov starting in FY2000. However, data quality steadily improves over that decade, particularly in the commonly referenced fields of interest to this study. In most cases, unlabeled rates topped out at 5% to 10%. The critical exceptions are the B*ase and All Options* and *Base and Exercised Options* fields, which report contract ceilings. Prior to FY2007, these fields are blank for the majority

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[7] These exclusions are common with other DIIG work. See DIIG methodology for more details: http://csis.org/program/methodology

of contracts. When that field is not available, calculating the percentage growth rate due to cost-ceiling–raising change orders is impossible. In addition, this study classifies contract size by initial ceiling and not total obligations because the latter figure is dependent on contract performance.

Because a key dependent and independent variable are not available prior to FY2007, the study team chose to set FY2007 as the start date rather than risk sample bias by including only those earlier contracts which were properly labeled. This restriction poses a significant limitation in that no contracts of more than seven years in duration can be included and five-year contracts are only in the study period if they started by October 1, 2007, or were closed out early.

The dependent variables, as well as the other study variables, are available through the project's GitHub page (Sanders, 2015). The entire dataset includes nearly six million contracts, and as a result the study team will also provide smaller samples as a more accessible starting point. The means of sampling will be determined by consultation with members of the likely user community at the NPS conference and the interviews during the refinement phase of this project.

The largest sampling challenge is that approximately two-thirds of the contracts have a total obligated value less than $25,000, but these contracts represent only about 3% of the obligations for the period. As a result, when this paper deals with samples for computation reasons, the sample is weighted by total obligations to better reflect DoD spending patterns rather than merely describing the numerous, but comparatively insignificant in aggregate, small contracts. The Bayesian model developed later in this paper is calculated using the complete dataset but includes a variable differentiating by initial contract ceiling, which is intentionally constructed to ease study of larger contracts.

This approach addresses two of the largest obstacles to wider use of FPDS within the government, academia, and industry. First, the two official portals, USAspending.gov and the FPDS web-tool, both perform a critical service in giving access to contract transaction in aggregate or detailed form. However, for many researchers the relevant unit of analysis is contracts and not transactions. Both websites can be used to access the full records of individual contracts, but due to data inconsistencies and bulk download restrictions, they are not well suited to larger sample studies.

The limitations of the data in raw form can be overcome by downloading the complete data feeds via the data tab of USAspending.gov, but with each year accounting for multiple gigabytes, this represents a high barrier to entry for researchers who lack the tools or training for large dataset work. This challenge is further increased by the often arcane nature of the data fields and the need to undertake cleanup and refer to multiple columns to get to data of interest. This first challenge is attested to by the regular calls the study team receives from other researchers seeking to use FPDS.

The second obstacle is that FPDS almost exclusively measures contract inputs but not performance outputs. Measures of contract performance do exist in other databases, but they are largely inaccessible without, at very least, an official government purpose or permit. This project takes a step towards overcoming that problem through three dependent variables referenced earlier in this section. These variables were chosen due to their relevance to fixed-price contracting and availability, but they are also applicable to a wider range of research questions. Due to their importance and broader reference, this paper discusses each of the three in detail in a subsequent section.

Single-Offer Competition

Whether or not a contract is competed is primarily an input into performance. However, single-offer competition also reveals information about the request for proposals. A solicitation that only has a single respondent indicates some combination of three factors: thinness in the underlying market; a failure to notify or give adequate response time to potential competitors; or a contract that is unappealing to vendors. That final point is of interest to this study. Fixed-price contracts transfer risk to vendors, and if vendors perceive greater risk than the government is willing to pay for, then fewer vendors may be willing to bid.

Methodology

Non-competed contracts are not included in this analysis because the choice of whether or not to compete is based on factors that are already known before the choice between fixed-price and cost-based contract is made. For example, when a sole-source award is justified based on there being "only one source," that rationale refers to the total number of potential vendors and not the number of interested vendors. As a result, for the graphs on single-offer competition and for analysis at the end of this piece, sole-source awards are excluded. While multiple variables are used to judge whether a contract has been completed, only one, the *Number of Offers Received*, is necessary to determine how many vendors really did submit an offer.

Whether a contract is competed is calculated largely using the same approach as in prior CSIS studies ("Methodology," n.d.). This method emulates the official DoD methodology to the extent possible when using raw data downloads rather than the FPDS webtool. In the vast majority of cases, competitive status is classified for the entirety of the contract duration. Thus if a contract had a duration of three years and was competed in the first year, it qualifies as competed for the entirety of the duration. This also extends to single-award indefinite delivery contracts, which are classified based on whether the original vehicle was competed rather than consistently treated as only receiving an offer from the single awardee. The Number of Offers Received is calculated using the same strategy.

To see more details on the construction of the number of offers, visit Contract_Competition.md on the project's CSISdefense/Fixed-Price GitHub page ("Fixed-price/Contract_Competition.md.," 2015). Summary charts are included in the parallel CSIS report on Competition, which is also in the conference proceedings.

Terminations

Abruptly ending a contract through termination is a challenging endeavor for the government. The proximate cause of the termination may not be vendor performance, but instead a drastic change in government needs, the failure of a related contract, or the cancellation of the entire program. However, in all three cases the government has the option of simply running out currently exercised options and stopping further payments. Thus, even if the source of the failure was outside the contract, a termination indicates that the contract was unable to adapt to changing circumstances. Critically, the greatest vulnerability of fixed-price contracting will result in a termination: if too much risk is placed on the vendor and they outright fail beyond the point at which adjusting the contract could turn things around. In this instance, the government may lose any resources that have already been invested as well as paying a significant cost in time to start the project over.

Methodology

Contract termination is determined using the *Reason for Modification* field in FPDS. A contract is considered to be terminated if it has at least one modification with the following values:

- "Terminate for Default (complete or partial)"
- "Terminate for Cause"
- "Terminate for Convenience (complete or partial)"
- "Legal Contract Cancellation"

These four categories and the "Close Out" category are used to mark a contract as closed. As is discussed above, many contracts well past their current completion date never have a transaction marking them closed, however, a termination is an active measure that mandates reporting unlike the natural end of a contract which can go unremarked.

The four different values of contract termination provide useful granularity, but for aforementioned reasons even a partial termination for convenience indicates that something has likely gone awry. Thus, given the already low number of terminations, the study team treats a contract as either terminated or it is not, rather than subdividing by type.

To see more details on the construction of the number of offers, visit Contract_Competition.md on the project's CSISdefense/Fixed-Price GitHub page ("Fixed-price/Contract_Competition.md.," 2015).

Cost-Ceiling-Raising Change Orders

Change orders are not as severe an indicator of trouble as terminations. A change order might result from a contract being adapted to a changing environment or even being adapted to further take advantage of a successful innovation. Even when the change order indicates a mistake, it may often not be on the vendor side. Instead, requirements creep prompted by the government may add expensive new tasks to the contract. The affordability of fixed-price contracting comes in part from their simplicity and inflexibility. Thus, when fixed-price contracts are subjected to a large number of change orders, whether prompted by government or vendor actions, this is a warning sign that a different form of pricing may have been more affordable.

Methodology

Similar to contract terminations, change orders are reported in the *Reason for Modification* field. There are two values that this study counts as change orders: "Change Order" and "Definitize Change Order." For the remainder of this report, contracts with at least one change order are called Changed Contracts.

There are also multiple modifications captured in FPDS that this current study will not investigate as change orders. These include:

- Additional Work (new agreement, FAR Part 6 applies)
- Supplemental Agreement for work within scope
- Exercise an Option
- Definitize Letter Contract

The Number of Change Orders refers to the number of FPDS transactions for a given contract that lists one of the two change order categories as their *Reason for Modification*. The vast majority of contracts do not receive change orders, but changed contracts are still far more common than terminations.

This study uses changes in the *Base and All Options Value Amount* as a way of tracking the potential cost of change orders. The *Base and All Options Value Amount* refers to the ceiling of contract costs if all available options were exercised. The alternative ceiling measure, *Base and Exercised Value Amount,* is not used because contracts are often specified such that the bulk of the eventually executed contract, in dollar terms are treated as options. In these cases, the all-inclusive value provides a better baseline for tracking growth.

The *Obligated Amount* refers to the actual amount paid to vendors. This study team does not use this value for this analysis because spending for change orders is not necessarily front-loaded. For example, a change to a contract in May of 2010 could easily result in payments from May 2010 through August 2013.

The % Growth in Base and All Options Value Amount from Change Orders is calculated as follows:

$$\% \ Growth = \frac{Base \ \& \ All \ Options \ Value \ Increases \ from \ Change \ Order \ Modifications}{Base \ \& \ All \ Options \ Value \ Amount \ for \ Original, \ Unmodified \ Transaction}$$

To see more details on the construction of the number of offers, visit Contract_ChangeOrders.md on the project's CSISdefenses/Fixed-Price GitHub page ("Fixed-price/Contract_Competition.md.," 2015).

Bayesian Network Model Building

A variety of statistical techniques are appropriate for inferential analysis on when fixed-price contracts are most likely to be successful. The study team chose a Bayesian network approach for three key reasons. First, this approach scales well to large datasets, such as the nearly six million defense contracts completed between FY2007 and FY2013. Traditionally, only a sample of such data would be available, but thanks to FPDS and modern computing, it is possible to analyze the entire population. Second, while a Bayesian network approach and other similar techniques can be used for prediction, it is particularly well suited to understanding the how the different pieces of evidence are interrelated. Because this project seeks to provide a starting point for future research, enhancing understanding of the model's causal logic is more important than creating a model which optimizes the ability to predict outcomes.

Finally, the knowledge engineering process used with Bayesian models—building connections between evidence, called whitelists and blacklists, and the subsequent model queries—is well suited to CSIS's strength in accessing acquisition domain experts and data scientists. The initial model in this paper will be built upon over time in two ways. First, it will be expanded from examining only the Number of Offers Received to including all three dependent variables. Second, it will be refined by consultation with additional external experts and listening to their insight about which pieces of evidence should be connected and where more granularity may be appropriate.

The model is built in the open source statistical programming language R using two modules. The module BnLearn is used for the Bayesian network learning process, which turns the collected data into a directed graph that is acyclic, which is to say there are no loops (Scutari, 2010). The module gRain is used for the second part of the process, creating the conditional probability table and then querying the resulting multiples (Højsgaard, 2014). Both modules are also open source and the data as well as the processing and analytic programming code used to implement this process are available through the CSISdefense fixed price GitHub repository (Sanders, 2015).

Description of Evidence

As with most statistical models, the first step with a Bayesian network is to gather, clean, and transform the data. Each piece of evidence was collected by first applying CSIS transaction-level lookup tables. Once the transaction level data was categorized in SQL server, it was then collated into contract-wide values. The first step in this process was done using codebooks available at the lookup-tables repository of the CSISdefense GitHub account. The combination stage was done on a variable by variable basis and that process is covered in the fixed-price repository of the CSISdefense GitHub account. The last stage was conversion into evidence notes, each having between two and eight distinct states. The processing required for a Bayesian network increases exponentially with each new node of evidence. As a result, the initial model is intentionally minimalist, and our study team will add more granularity to the model as developments warrant.

Contract Fundamentals

These nodes of evidence are largely set by the needs of the relevant portion of the Department of Defense rather than chosen by the acquisition official. There are choices to be made within them, for example, whether to fill a need directly with as a product or via a service provider. However, as a rule these nodes of evidence influence the contracting method and not vice versa.

Who (Component: Army/Navy/Air Force/Other DoD): Determined by the contracting office rather than the funding office. This will be referred to as "component" throughout this discussion.

What (Platform: Air/Land/Vessel/Electronics & Communications/Missiles and Space/Weapons and Ammunition/Facility Related Services & Construction/Other): Determined by the combination of the claimant program code for the platform when available and otherwise via the product or service code. This will be referred to as "platform" throughout this discussion.

PSR (Product/Service/R&D): Determined by the product or service codes, with R&D management and support being treated as a service.

Intl (International: Just U.S./Some International): Based on the place of performance. Those contracts with any transactions in foreign countries are treated as having some international. Lookup tables are primarily used when imputing data is necessary due to a missing or malformed value in either the country or U.S. state place of performance fields.

Link (# of linked contracts: none/1–749/750+): This calculated column is the study team's first effort to account for the possibility of problems cascading from other related contracts. For those contracts without a system code, the value is set equal to the number of preexisting contracts in the same contracting office that share a Platform characterization (excluding the Facility-related Services and Construction [FRS&C] and other platforms). For those contracts with a system equipment code, the value is equal to the number of preexisting contracts sharing the system equipment code. This value is then supplemented with the number of contracts with the same platform and contracting office (with the aforementioned exclusions) that are not labeled with any system or equipment code. This field will be referred to as "Interlinkages" throughout this discussion.

See the fixed-price repository of the CSISdefense GitHub account for processing code used for this calculation.

Contract Approach

The contract approach refers to those contract characteristics that are chosen by the relevant acquisition officials in the pursuit of a successful outcome.

Comp (Competition: Comp./No Comp.): Is determined using the standard CSIS methodology, with the critical exception that the numbers of offers received is treated as a separate piece of evidence.

Ceil (Ceiling: $15,000/$100,000/$1,000,000/$30,000,000): Refers to the initial ceiling on total potential contract obligations. Is set by the initial Base and All Options Value for the contract. This value was chosen rather than the initial Base and Exercised Options Value because exercising options happens regularly during the course of an on-time and on-budget contract.

Dur (Duration: One day to Two Months/Seven Months to a Year/More than a Year): Refers to the duration and is calculated using the number of days between the initial effective date and the current completion date for the contract. The ultimate completion date is also available but was regularly unlabeled.

FxCb (Fixed price or Cost-base): Fixed price includes all forms of fixed-price contracting except fixed-price level of effort. That comparatively rare form has been described in meetings with DoD officials as exhibiting more properties of cost-based contracts. Cost-base includes all forms of cost-plus contracts as well as time and materials and labor-hours contracts.

Indefinite Delivery Vehicle (IDV): Indicates whether or not a contract is one of the many forms of Indefinite Delivery Vehicles (IDVs). This is a contracting approach in which a single root contract is used as a basis for multiple other contracts.

Contract Outcomes

Offr (Number of Offers Received: 1, 2, 3–4, 5+): This is the first dependent variable and is described in greater detail earlier in this document. Cases with no competition are categorized as only one offer, although for hypothesis purposes, the existence of competition will typically be included in the model query. The remaining dependent variables will be added in to the model in coming research stages.

The Whitelist of Mandatory Arcs Between Pieces of Evidence

The whitelist is a collection of directed arcs between pieces of evidence that must be included in the final model whether or not the learning algorithm recommends them. Developing the whitelist was an iterative process. First the team determined which pieces of evidence were most strongly linked and then, after seeing initial results, added further connections where the learning algorithm could not determine the flow of causality. Finally, the team compared different versions of the model created using variant algorithms and added those arcs which the study team deemed important but that were absent in some models. The whitelist in Figure 1 is the final one at the time this paper was written, including all three iterations of building the list.
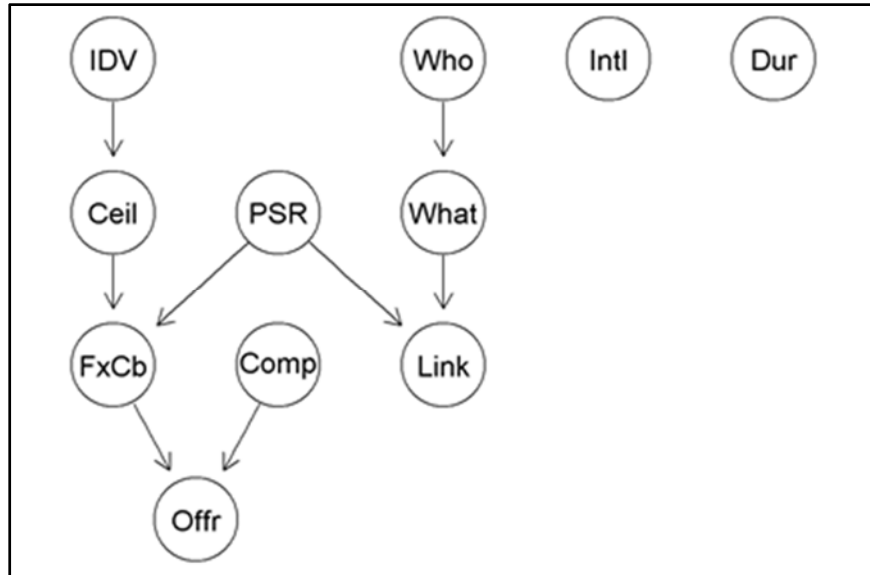
Figure 1. Whitelist of Arcs That Must Appear in the Bayesian Model

In interpreting this graph, each circle is a piece of evidence or node. Each arrow is a directed arc, and the parent node influences the child node that the arrow points to. For example, there is an arc from the parent Component ("Who") node to the child Platform ("What") node because the different components buy different mixes of platforms. Thus if Component is "Army" then the Platform is substantially more likely to be "Land Vehicles" and less likely to be "Vessels." So long as no loops are formed, each node can be linked to multiple or no other nodes, for example Product/Service/R&D (PSR) influences both "Fixed price or Cost-base" and Interlinkages ("Link") and "Number of Offers Received" (Offr) has arcs coming from both comp and "Fixed price or Cost-base."

Working from the bottom, "Number of Offers Received" has "Fixed price or Cost-base" and Comp as its parents because the number of offers directly depend on whether a contract is competed and "Fixed price or Cost-base" is the study variable, and thus the connection with the dependent variable is highly of interest. On the next level up, Interlinkages is a constructed variable and both Platform and PSR are used to create it. Who also plays a role, but primarily at the contracting office level and thus the connection is not as direct. "Fixed price or Cost-base's" arc from PSR was there from the start, as R&D contracts are classically the domain of cost-based pricing. "Fixed price or Cost-base's" second parent, Ceiling, was added near the end of the process because "Fixed price or Cost-base" only had one parent in some of the models and consistently including Ceiling in the rest. Further analysis via cross-sectional graphs showed that after accounting for PSR, Ceiling appeared to have the strongest influence on "Fixed price or Cost-base." Namely, contracts with high ceilings are notably more likely to be Cost-Based or Combination.

Platform is influenced by Components in another straight forward connection as was covered in an earlier example. IDV is a parent of Ceiling because the learning algorithm could not decide on the direction of the relationship. The study team decided that IDV was the parent because choosing an IDV can often mean choosing to break a goal into multiple smaller pieces, each with a small scope. Thus the Ceiling of a project can depend on whether or not the contracting officer feels an IDV is available and appropriate. The last two nodes, Intl and Duration, do not have any whitelist entries at this time. During model creation, the study team experimented with linking Duration to "Number of Offers Received,"

but that caused the learning algorithm to reject the stronger connection between Ceiling and "Number of Offers Received." The team could force both connections, but it is not necessary to do so and the relationship between Duration and "Number of Offers Received" appeared complex in cross-sectional graphs. As will be shown later, this does leave Duration without any children, but this problem will likely be remedied once additional dependent variables are added.

The Blacklist of Mandatory Arcs Between Pieces of Evidence

Black lists are the inversion of white lists: arcs that may never be included in the model regardless of the findings of the learning algorithm. Developing the blacklist was similarly an iterative process, although with one notable exception, most of the revisions were merely adding more arcs to the blacklist to correct for possibilities overlooked in prior iterations.

For Figure 2, the red lines indicate arcs that are not allowed. For example the arrow from "Number of Offers Received" to Platform means that the number of offers cannot have a causal influence on what sort of platform is being bought. In many cases, this is for straightforward causal reasons. The evidence regarding contract fundamental can influence the contracting approach, but not vice versa. This graph is has many more arcs than the prior Whitelist graph because it is straightforward for experts to establish which evidence factors are decided earlier along the timeline or are take precedence over deciding other related factors. For example, the relevant acquisition official will typically first determine whether they can compete a given contract and only then determine what vehicle or pricing mechanism would be appropriate.

The existence of a blacklist arrow does not mandate that there is a connection going the other direction. In fact, that is the point of the blacklist, to prevent spurious connections from being made without committing to an arc going in the opposite direction. For example "Number of Offers Received" is blacklisted to every other piece of evidence in the model, because competition takes place only after the other factors are set in broad terms. However, as will be seen in the causal model, not every piece of evidence that can arc to "Number of Offers Received" does so.
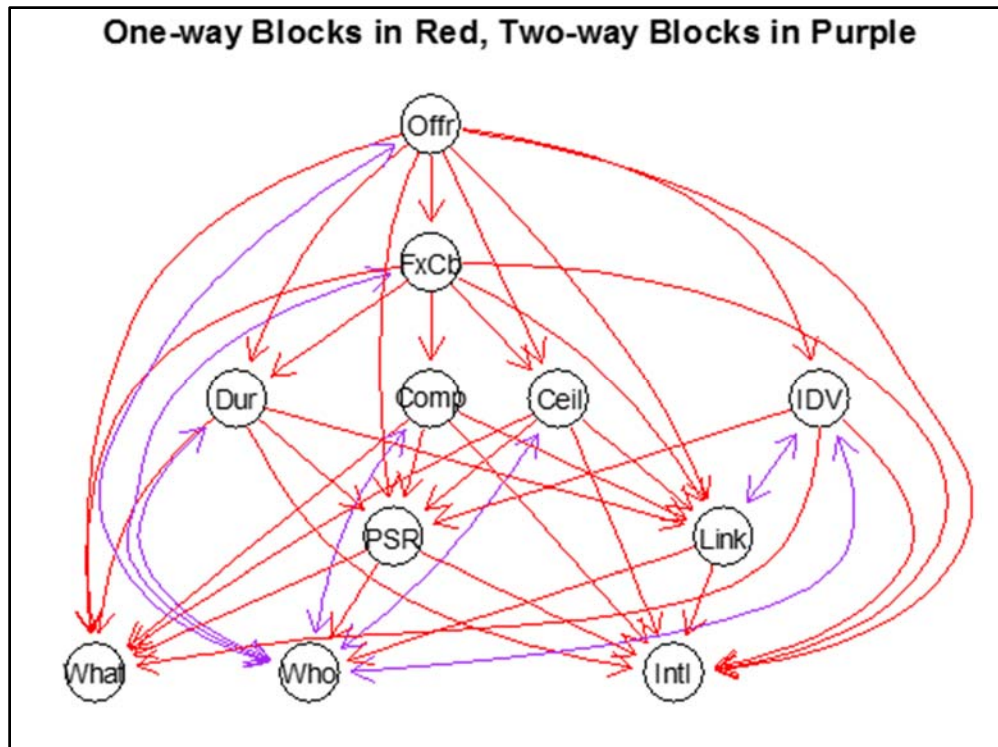
Figure 2.   Bayesian Network Blacklist

In a smaller number of cases, the blacklist extends to arcs in both directions. This means that the two evidence nodes, connected with a purple arc and an arrow pointing in both directions cannot be parents nor children of each other. In the case of IDV and linked, this is because the causal link is difficult adjudicate because of confounding factors. For contracting office and platform pairings that have IDVs available, the number of preexisting interlinked contracts will typically be higher. However, that reflects the omitted variable of whether there are active IDVs rather than a direct connection between the two evidence nods.

Component evidence node has bidirectional blacklisted arcs with all of the contracting approach evidence nodes as well as with the "Number of Offers Received" outcome node. The study team chose to block these links because the literature review did not find a theoretical basis for the organization itself, rather than the characteristics of its contracts, being a key determiner for fixed-price success or failure. CSIS is separately examining that question in its report on DoD components, which is also being presented at this conference. Pending the outcome of that study, these bidirectional blacklisted arcs may be revisited.

Initial Results

After the iterated whitelist and blacklist generation process, Figure 3 shows the ultimate result. In the figure, the blue arrows are those arcs that were mandated by whitelists. With the exception of links to Duration from Ceiling, IDV, and Comp, the direction of the remainder of the arcs was locked in by the blacklist. Thus, PSR did not have to have a direct connection to Duration, but the alternative was disallowed.

The resulting Bayesian network is highly interlinked, as is shown by the sheer number of arcs, well in excess of the small number required by the white list. However, there

are two notable areas where connections are sparse. Duration is influenced by six different evidence nodes but does not influence Offr or any other node. This may change in the future as a result of introducing greater granularity to Duration or after the introduction of the other dependent variables. The second evidence node that is remarkably isolated is "Fixed price or Cost-base," which suggests humility may be necessary regarding the influence of the study variable.
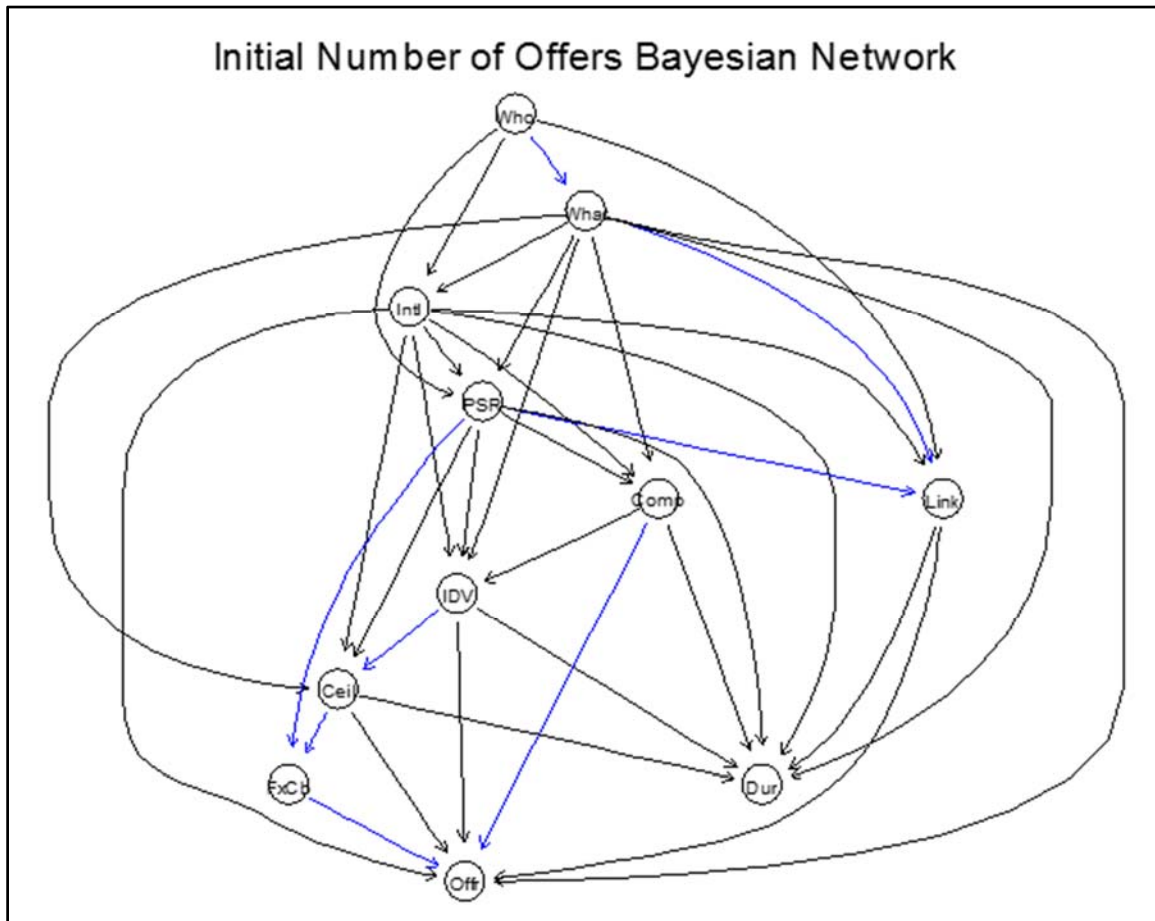

Figure 3. Initial Bayesian Network

Preliminary Hypothesis Testing

This initial model allows for preliminary testing of four of the five study hypotheses as well as robustness checking using five different controls. The study team developed each of these hypotheses and controls from the literature, rather than through learning algorithm described above.

As presently configured, the various evidence nodes are not granular enough to fully test the hypotheses proposed in the early stages of this research. However, four of the five hypotheses can be tested. These hypotheses were often formulated with a greater level of specificity than the model presently allows, for example, examining contracts with a ceiling of greater than $500 million or addressing only software contracts. Categories which only apply to a small fraction of contracts can increase the complexity of the model while reducing its statistical power. This trade-off can be worthwhile, but it will first be tested with model variants and only when most insightful will these additional breakdowns be included in the model as a whole.

The current Bayesian model enabled five different controls which were employed by comparing fixed price and cost-based Number of Offers Received for a different subsets of the contract dataset. As the Bayesian model becomes more inclusive, more controls, such as separating undefinitized contract actions, will be added.

- Past research has found aircraft and drone contracts to be especially challenging,[8,9] so the first control split the dataset using the Platform evidence node (DoD, 2015; Ritchie, 1997).

- Both larger and smaller contracts sometimes show different trends than those in the middle. The second control separated out large contracts as those with a ceiling of/over $30 million. The third control separates out contracts with a ceiling of less than $1 million.[10]

- Indefinite Delivery Vehicles are associated with higher rates of competition and are separated out for the fourth control.[11]

- Finally contracts with a duration of greater than a year may have higher risk thus experience different dynamics.

Hypothesis 1: Large R&D contracts will perform better as cost-based contracts.

Our interim findings generally support both the academic literature[12] and policy documents[13] that posit large R&D contracts may perform better under cost-based contracts. As expected, cost-based contracts had a substantially lower single offer competition rate, 22.5% for cost-based versus 29.7% for fixed price. Cost-based similarly had a higher rate of competition with five or more offer. This pattern held for long duration contracts and for aircraft contracts. In the latter case fixed-price contracts received only a single offer 37.6%

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[8] Aircraft have a 22 point corresponding effect on total contract growth that is explained by schedule and cost overruns. The report looked at time, schedule, and differences between major commands, but not contract pricing mechanism.

[9] During WWII, fixed-price contracts were favored for aircraft, but due to factors relating to the "degree of organization by weapons companies," only Britain was able to develop primarily fixed-price procedures.

[10] For overall DoD contracting in 2013, contracts with an annual value of less than $250,000 saw the highest rate of competition with two or more offers (62%), and that rate generally declines as size of contract increases (CSIS Analysis of FPDS Data). That breakpoint did not align with the buckets of the Ceiling evidence node and the lower than $1 million captured this dynamic more effectively than lower than $100,000.

[11] Past CSIS research has found that contracts using a purchase orders and "Other IDCs" (Other IDCs includes Federal Supply Schedule, Basic Ordering Agreements, Blanket Purchasing Agreements, Government-Wide Acquisition Contracts) have notably higher rates of single-offer competition than other vehicles (CSIS, Federal Services Contracting and the Supporting Industrial Base, 2000–2012). Multi-award IDVs however have notably higher rates. This hypothesis will be retested when greater granularity in the vehicle evidence node is available.

[12] "In particular, we find that the [contracting office] principal prefers a cost-plus contract in cases of large R&D projects or rising innovation benefits. … The agent increases its research out-lays in response to a higher sharing rate when the expected rewards from innovation significantly exceed research costs" (Goel, 1999).

[13] USD(AT&L) describes low technical risk as a reason to choose fixed-price contracts. Large R&D contracts are known for their technical risk (Kendall, 2015).

of the time versus 11.3% for cost-based! In these categories and in the overall sample, combination contracts more closely resembled fixed-price contracts when it came to offers received. Cost-plus only loses its advantage for IDV contracts, where 26% of contracts receive only a single offer compared to 24.9% of combination contracts and 20.5% of fixed-price contracts. This discrepancy merits further study to determine what sort of IDV drives up the rate of single offer competition for cost-plus contracts.

Hypothesis 2: Complex projects, as measured by pre-Milestone B major defense acquisition project status, will perform better as cost-based contracts.

Complex projects, such as the development stage of Major Defense Acquisition Projects, are favored for cost based contracts in the literature (Bajari & Tadelis, 2001)[14] but not supported by our analysis when the placeholder of linkages was used. However, the results were not highly robust and were contradicted for two of the five controls. The single offer competition rate for cost-plus contracts was six percentage points lower for large contracts and two percentage points lower for aircraft. Since both large contracts and aircraft and drone contracts are associated with MDAPs, this suggests that the study team will need to refine linkages or test the hypothesis directly by looking at system equipment codes.

Hypothesis 3: Contracts with a longer duration will perform better as cost-based contracts.

While prolonged schedules and unforeseen cost growth are reasons a vendor may prefer cost-based contracting,[15] the hypothesized relationship did not hold. Unlike Hypothesis 2, the results appeared to be fairly robust. Overall, 25.3% of fixed-price contracts with durations greater than a year receive only one offer compared to 31.4% of cost-plus contracts. This gap narrows to less than a percentage point for large contracts and aircraft and drone contracts,

Combination contract rates resembled fixed-price rates in most categories, with the exception of aircraft and drones where more than half of all competed contracts received only one offer. Further analysis may be merited to determine whether the hypothesis holds when the threshold is set at two or more years.

Hypothesis 4: The potential for greater competition improves fixed-price performance.

The hypothesis that fixed-price contests are preferred by acquisition officials when they are likely to receive more competition[16] may indicate that contracts that are more likely to be competed will perform better. This hypothesis is not testable with this dependent variable. However, given the high variability for the Number of Offers Received for fixed-price contracts and the number of evidence nodes influencing both competition and number of offers, this hypothesis should be straightforward to test in future stages.

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[14] Cost-plus contracts are preferred to fixed-price contracts when a project is more complex.
[15] "But price redetermination might be used whenever contingency charges otherwise would be included in a contract price due to such factors as prolonged delivery schedules, unstable market conditions for material or labor, or uncertainty as to cost of performance" (Fixed Prices and Price Redetermination in Defense Contracts).
[16] "[Government principals] would prefer a fixed-price contract when the number of bidders increases" (Goel, 2001).

Hypothesis 5: Large software projects perform better as fixed-price contracts.

Our results surrounding this hypothesis were inconclusive. We based the hypothesis on one piece of literature which stated that vendors prefer fixed-price contracts for software,[17] contradicting other literature that hypothesized that venders prefer cost-plus contracts for larger, more complicated projects. For this iteration, Electronics and Communications services were used as a proxy for software. We found that for small contracts, the hypothesis holds, with fixed-price contracts nearly 10 percentage points less likely to receive one offer compared to cost-based (28.8% versus 38.7%). However, this relationship reverses itself for large contracts; 29% of fixed-price contracts receive only a single offer versus 21.2% of cost-based contracts.

Conclusions

This promising hypothesis testing shows the value of the Bayesian network built by the study team. The analysis of single-offer competition for larger R&D contracts confirmed the conventional wisdom that vendors would be less likely to bid on fixed-price contracts but also revealed an intriguing wrinkle that this does not hold for large IDV R&D contracts. In addition, both the model building and the hypothesis testing surprisingly failed to uncover a relationship between contract duration and the number of offers a contract received. Both the literature and practitioners have often mentioned the importance of contract duration, and it may prove more consequential for contract terminations and ceiling-raising change orders which the study team will explore as this work continues.

Finally, the study team is excited to pursue the next steps of refining the model via external consultation and also expanding the model to include the remaining two dependent variables as well as a small number of intervening variables. The latest version of the model will be available at the CSISdefense GitHub account, and CSIS welcomes feedback from readers.[18]

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[17] "We hypothesize that the vendor's ability to leverage information asymmetry about capabilities and experiences translates into the vendor preferring Fixed-Price contract to secure larger information rents. Our results support this hypothesis and suggest that the vendor would prefer the FP contract for larger and longer projects with larger teams. However, vendors would prefer a [Time and Materials] contract when the risk of employee attrition from the project team is high" (Gopal & Sivaramakrishnan, 2006).

[18] Please visit https://github.com/CSISdefense/Fixed-price to see the latest version of the model and submit any questions or suggestions to gsanders@csis.org. For timing reasons any feedback that is not received by mid-summer 2015 is unlikely to be included in the final technical paper, but may be incorporated in future iterations of this work.

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