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Technical Data as a Service (TDaaS) and the Valuation of Data Options

17 June 2019

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Abstract

Technical data allow the Department of Defense to sustain the systems it acquires and provide flexibility for future acquisitions; however, acquiring these data is challenging. Current DoD policy requires program managers (PMs) to consider procuring technical data and associated data rights during acquisition, and current practice is to negotiate for and acquire a complete Technical Data Package (TDP) in anticipation of future unspecified needs. However, because those needs are uncertain, it is difficult to determine a fair and reasonable price. Some data that are eventually needed may not be acquired, and some data that are acquired may never be used.

New digital data technologies can overcome these challenges, but only if paired with new acquisition approaches. Today's data management systems make it possible to define and manage digital subsets of the TDP—Technical Data Sets (TDSs)—that are tailored to the Government's specific data needs, or use cases. The ability to contract for optional delivery of TDSs as needs arise will require valuation methods that allow PMs to negotiate pricing under conditions of uncertainty.

To help meet these challenges, this research develops and demonstrates a new approach to the valuation of technical data, based on the application of real options theory. A key objective is to show how this approach, together with the application of technical data use cases and the capability of new data management tools, allows DoD PMs to hedge against uncertainty and acquire technical data on more favorable terms. The results include an algorithm for implementing the approach under a wide range of circumstances, and an example that shows how that algorithm can be used to answer practical questions that the PM faces when acquiring technical data (for example, Which data, if any, should be acquired now? Should the government negotiate options to access certain data downstream? If so, how should industry and government arrive at a mutually acceptable price?) Finally, the paper shows how this approach supports the development of a powerful new business model—Technical Data as a Service (TDaaS).

The methods, tools, and frameworks developed herein provide several benefits.

First, they help DoD purchase only the data that are needed, when they are needed, and for how long they are needed, thus enabling significant potential savings in system life-cycle costs.

Second, they allow DoD to respond to unanticipated needs by preserving options for future data access and/or ownership.

Third, they help industry and Government arrive at a fair and reasonable price by allowing both parties to more accurately assess data value and risk from their own unique perspectives.

Fourth, they are consistent with, and help to achieve the benefits of, related DoD initiatives in acquisition and digital engineering. These indirect benefits include not only acquisition cost savings but also improved trade space exploration and reduced acquisition cycle time.

Finally, it should be noted that the results of this research can be directly incorporated into upcoming DoD pilot programs aimed at implementing Congressionally-directed improvements in technical data acquisition and intellectual property valuation.

Keywords: technical data, technical data package, technical data set, intellectual property, valuation, pricing, real options, technical data as a service, digital engineering, product life-cycle management, digital thread, digital twin

About the Authors

Mr. George E Thompson has over 40 years' experience conducting studies and analyses in national defense and homeland security. His clients have included the U.S. Air Force, the Joint Staff, the U.S. Special Operations Command, the Defense Advanced Research Projects Agency, and the Department of Homeland Security. He has led or held key roles in a large number of acquisition, cost-effectiveness and operational analyses associated with DoD programs, weapon systems, and technologies. He holds an MS in applied mathematics from Purdue University.

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Background

In the context of DoD acquisition, the term technical data is defined as "recorded information, regardless of the form or method of the recording, of a scientific or technical nature" [1]. Of particular interest are "form, fit, and function data," defined as "technical data that describes the required overall physical, functional, and performance characteristics…of an item, component, or process to the extent necessary to permit identification of physically and functionally interchangeable items" [2]. A collection of technical data that fully and authoritatively describes an item in a manner that is "adequate for supporting an acquisition strategy, production, and engineering and logistics support" is termed a Technical Data Package (TDP) [3]. As these definitions suggest, a TDP is often critical to the effective installation, operation, maintenance, repair, and modification of a DoD system.

Typically, much of the data within a TDP falls within a specific category of intellectual property (IP) called "trade secrets." This term embraces a wide range of formulas, patterns, compilations, programs, devices, methods, techniques and processes that meet a certain legal standard. The most common standard is that a trade secret "derives independent economic value…from not being generally known to…other persons who can obtain economic value from its disclosure or use…" [4].

The acquisition of technical data, including the legal right to use and/or distribute those data, is fraught with challenge. A major difficulty is that much of Government's need for the data—for example, to make repairs or modifications, or to enhance competition in other acquisitions—lies in the future. In other words, the nature and timing of the Government's need is inherently uncertain [5]. In addition, as McGrath and Prather [6] point out, "price negotiation for the TDP often occurs in a sole source environment, with conflicting assertions by the contractor and government over rights in data." Van Atta [5] cites recent examples in which equipment manufacturers have quoted prices of as much as $2 billion for technical data—accompanied in one case by the statement that the manufacturer had no intention of actually selling the data at all. The net result, per McGrath and Prather, is that “TDPs that are needed are often not acquired, TDPs that are acquired are often not properly priced, and TDPs that are delivered may never be used.”

At the same time, technology trends have caused a fundamental shift in way technical data are managed. Aerospace and defense industries no longer use engineering drawings; rather, computer aided design (CAD) and computer aided engineering (CAE), along with a model-based approach to engineering and manufacturing, are now the norm. CAD and CAE systems generate the “digital thread” or “digital tapestry” that drives modeling, analysis, and manufacturing processes [7-8]. The DoD Digital Engineering Strategy (DES) [9] envisions a corresponding shift from a development methodology of design-build-test to one of model-analyze-build. A key enabler is the growing use of Product Lifecycle Management (PLM) systems, which control and manage digital data for use during the engineering, manufacturing, and product support phases of the product life cycle [10]. PLMs allow industry to define Technical Data Sets (TDSs): subsets of the total TDP that can be structured around particular needs. In theory, these TDSs could be defined at any point—including the actual time of need—and made available for purchase or short-term lease, as the needs and interests of the Government dictate.

In short, the current situation combines challenge (the difficulty of valuing technical data deliverables and usage rights under conditions of uncertainty regarding future needs) and opportunity (new technologies and tools that can make tailored data sets available as these needs arise). The Under Secretary of Defense for Research and Engineering (USDR&E), Michael Griffin, has made it clear what needs to be done:

> “Government sponsors must determine data needs based upon anticipated prototyping activities and outcomes, and consider these rights in the establishment of contracting and service level agreements. One of the biggest challenges is that specific data rights needs are often not known at the time of contract award, when there is the most leverage to negotiate the best price for, subsequent access to, and use of the [intellectual property (IP)]. Accordingly, the DoD must move to a model that allows for negotiating options for

> access to IP during competition, then exercising those options as needs are realized." [11]

The outstanding question is how to accomplish this goal. This research aims to provide the necessary "how" by generalizing and demonstrating a new approach to technical data valuation under conditions of uncertainty, based on the application of real options theory.

Literature, Law, Policy, and Practice: A Brief Review

The following review addresses four threads that were introduced in the Background section: law and policy pertaining to DoD acquisition of technical data; the state of current DoD practice in this area; the valuation and pricing of intellectual property (including data rights); and real options theory.

DoD Technical Data Acquisition – Law and Policy

Hasik [12] provides an excellent summary of how the Government's stance on technical data and data rights for DoD weapon systems evolved over the period 1945 through 2014. In brief, the Government has moved away from a hands-off approach, through increasing assertion of Government rights in data, to the current requirement that acquisition of technical data be considered as part of all major defense acquisition programs. Hasik notes that the 2007 National Defense Authorization Act (NDAA) was a significant milestone, mandating that managers of major defense programs establish "acquisition strategies that provide for technical data rights needed to sustain such systems over their life cycle."

DoD Instruction 5000.02 [13] currently requires the development of an Acquisition Strategy prior to Milestone A (approval to enter the Technology Maturation and Risk Reduction phase). The strategy is updated at Milestone B (entry into the Engineering and Manufacturing Development (EMD) phase) and prior to any Request for Proposal release during EMD. The Acquisition Strategy includes a Technical Data Management Strategy that describes how the program will identify data requirements, acquire data (including appropriate data rights), assure the adequacy and accuracy of the data acquired, and manage the data. For large programs (Acquisition Category (ACAT) I and II), the Technical Data Management Strategy must address long-term data needs.

DoD Instruction 5010.12M [14] provides detailed guidance for defining data requirements, including specifying the intended use(s) of the TDP. This document also includes guidance on the acquisition of the data deliverables that comprise the TDP, including the use of Contract Data Requirements Lists (CDRLs) and Data Item Descriptions (DIDs).

In 2010, then Undersecretary of Defense Ashton Carter issued a memorandum titled “Better Buying Power…” [15]. In it, he stated that “At Milestone B, I will require that a business case analysis (BCA) be conducted in concert with the engineering trades analysis that would outline an approach for using open systems architectures and acquiring technical data rights (TDRs) to ensure sustained consideration of competition in the acquisition of weapon systems.” Two years later, the Better Buying Power 2.0 initiative [16] re-emphasized Government access to technical data as a means to ensure that DoD is positioned for competitive sourcing. Implementing guidance for the required BCAs has been published [17-18]; however, examples of completed BCAs are still very few.

Within the past few years, Congress has continued its attempts to address some of the problems described in the Background section of this paper. The FY 2017 NDAA [19] extended the provisions of the FY 2016 NDAA [20] that directed the Secretary of Defense to establish a Government-industry advisory panel (the so-called Section 813 Panel) to review applicable portions of the U.S. Code pertaining to rights in technical data and the validation of proprietary data restrictions.

While the Section 813 Panel was conducting its review, Congress prescribed important changes in DoD policy via the 2018 NDAA [21]. Section 835 of that act required DoD to negotiate a price for technical data deliverables before selecting a contractor for major weapon systems. It also included a preference for specifically negotiated licenses for technical data. The law did not include provisions for implementing these policies.

The final report of the Section 813 Panel was issued in November 2018 [22]. The panel addressed key “tension points” of disagreement between government and industry in a series of white papers. The panel observed that an underlying factor in these tension point issues is that DoD and industry have different business models, which oftentimes conflict. (See also the section of this paper titled “An Alternative Business Model…”) The panel identified areas of common ground, which formed the basis for recommended changes in statutes, regulations and policies, in order to balance the interests of the parties; however, its report did not identify specific valuation approaches that could help reconcile these perspectives.

DoD Technical Data Acquisition – Current Practice

Although DoD policy requires program managers (PMs) to define technical data requirements early in the acquisition process, this is quite difficult in practice. Van Atta [6] points out that the Government’s leverage is greatest prior to EMD. “However, at Milestone A and even Milestone B, the system is still developmental and there are uncertainties regarding its technical details. This can affect how much can be specified regarding the technical data needed for future sustainment.” The result, according to Hasik [23] is that “Neither the Government nor its potential suppliers can be certain of future costs and prices, as every actor in the system is planning, bidding, or negotiating with imperfect information about advanced technologies.” Moreover, as Van Atta adds, “…there is no guarantee that the competitors for the EMD contract will agree to provide the necessary data and rights under the conditions desired by DoD.”

A case-study analysis conducted by Gilbert [24] illustrates results that may be deemed typical. The analysis examined three pre-Milestone C programs (one each managed by the Navy, Army, and Marine Corps) with respect to their ability to integrate technical data in support of systems engineering activities. Gilbert found that although the technical data were readily available to the Government, there was very little correlation with the system model in each case, owing to “incomplete understanding of the data’s intended use.” In short, uncertainty regarding the use of technical data was found to limit is usefulness to the Government. (Gilbert did not address the question of whether it also complicated the process of negotiating a price.)

At a more aggregated level, Berardi et al. [25] conducted a statistical analysis of contracting trends in the wake of both Better Buying Power (BBP) initiatives and concluded that there are no clear trends in the levels of competition in the DoD. Ellman [26] actually noted a significant decline in the rate of effective competition for Air Force services over the period 2011-2015 and characterized it as consistent with the assumption that "most maintenance and repair for major aircraft platforms and systems will end up being performed by the original developer/manufacturer, for reasons including ownership of technical data rights."

In short, the evidence suggests that recent initiatives designed to reap the benefits of better technical data acquisition have yet to achieve their stated objectives. Berardi [25] concludes that one reason is that there are very few methods available for implementing the philosophies articulated in the BBP memoranda. Hasik [12] reaches a similar conclusion: "Given the complexity of the business case analysis that the [Department] now demands at every [major defense acquisition program's] Milestone B, some better tools would be important." Clearly, such tools will need to address the fundamental difficulty: the problem of uncertainty inherent in describing future data needs.

Intellectual Property Valuation and Pricing

The literature on IP valuation is vast, and much of it lies well outside the scope of this research, which focuses on technical data in the context of DoD system acquisition. A 2017 Aerospace Industries Association (AIA) white paper [27] provides a concise overview of IP valuation within this limited context. In particular, it describes the three IP valuation methods currently used by industry to determine the value of technical data for DoD acquisition. These include the "market approach" (estimating the market value of similar data), the "cost approach" (estimating the cost incurred in developing the data), and the "income approach" (estimating the present value of the expected income that can be earned from the data).

The definition of “trade secret” suggests, on its face, that the TDP price quoted by industry will reflect not only the value of the data (i.e., the magnitude of the economic advantage it confers) but also the risk of disclosure to a competitor (i.e., possibility of losing that advantage). In contrast with the subject of IP valuation, there is virtually no publicly available information on the specific methods used by DoD suppliers to assess disclosure risks as part of TDP pricing. Published frameworks and methods for the safeguarding of trade secrets [28] tend to focus on vulnerabilities arising from the activities of hostile nation states, malicious insiders, hackers, and transnational criminals (vice the DoD). The typical threat vectors addressed are cyber and physical attacks, human intelligence, eavesdropping, and wiretaps (vice the sale of data to the U.S. Government). Certainly there is indirect evidence that industry takes disclosure risks seriously. As one observer recently put it,

> “The same intellectual property that makes the technology and software in weapon systems so valuable to a service is also the life-blood of the manufacturer, providing for their long-term viability. Uncertain of what data rights are ‘necessary,’ the services’ appetite for data rights may be imposing unintended, but harmful, effects on the very defense industry that it relies upon for technological superiority.” [29]

It is not difficult to imagine the relationship between this perspective and the TDP pricing examples cited by Van Atta [6].

Turning to the Government’s perspective, the AIA [27] notes that the valuation methods used by industry are not directly applicable. A 2012 study by Head and Nelson [30] pointed out that “Currently, DoD has no standard method for determining the value of licenses for additional data rights. Each program office determines the details of its own approach…” Generally, according to the AIA, this consists of analyzing contractors’ detailed, bottom-up estimates of their supporting cost data. The Government may also compare the proposed TDP price with prices paid for “comparable” data packages. AIA notes that there are “a variety of concerns with this method,” including the fact that “cost of development is a very poor indicator of the value of the IP.” In addition to cost and price analysis, the Government may use a variety of methods to incorporate technical data rights provisions as a source-selection evaluation factor or assessment criterion, as described by Pickarz [31]. Again, because of the difficulty in valuing IP from the Government's perspective, this factor or criterion is usually scored adjectivally.

Section 802 of the 2018 NDAA [21] sought to address this problem by requiring the DoD to develop department-wide policies for purchase and licensing of IP. The stated goals for these policies were to: (i) enable coordination and consistency across the military departments; (ii) ensure that program managers are aware of the Government's IP rights; and (iii) utilize customized strategies that are based on the unique nature of the system and its components, the product support strategy for the particular system, the organic industrial base strategy, and the commercial marketplace.

The law does not specify how these policies are to be implemented, and in fact the defense acquisition community is only just beginning to come to come to grips with the problem. This topic was discussed at a November 2018 forum on "Defense Acquisition and Technical Data Rights," jointly sponsored by the AIA and the National Defense Industrial Association (NDIA) [32]. At the forum, members of a panel discussion on the Valuation of Intellectual Property in Defense Acquisition acknowledged that a standard DoD approach to technical data valuation is still pending the work of the "cadre of experts skilled in Intellectual Property valuation" that was directed by section 802 of the 2018 NDAA. Members of a different panel on "Recent Legislative and Policy Developments" further noted that such an approach should incorporate improved tools to predict technical data needs, including methods for dealing with uncertainty.

Real Options—Valuation Under Conditions of Uncertainty

Options theory grew out of the need to value options in financial markets. There, the purchase of an option allows the purchaser the right, but not the obligation, to buy or sell a stock at some future time, at a fixed price. The decision whether to purchase the option is based on the calculation of the option's value relative to its cost [33]. Real options theory extends this logic to other types of assets, such as factories, real estate, mines, and—importantly for this research project—intellectual property [34]. The theory also addresses the question of when the option should be exercised [33].

The traditional method to value stock options is the Black-Scholes model, first introduced in 1973 [35-36]. Variations of the Black-Scholes model are still widely used, but the basic assumptions of the model generally do not hold for the valuation of real options. The Black-Scholes model makes assumptions about constant volatility in price, normal distribution of returns and lognormal distribution of underlying asset value—assumptions that do not fit many real option scenarios. More importantly, the Black-Scholes model was developed to value a European-style option, which is an option that must be exercised at a fixed point in time. Real options, on the other hand, are usually better conceptualized as American-style options, which can be exercised at any point in time over the life of the option [37].

In recent years, researchers have begun to identify important applications of real options theory to DoD acquisition, in which future decision variables are often uncertain. Olagbemiro, et al. [38] proposed an application to DoD software acquisition, showing how the theory could be used to address issues of requirements uncertainty. Angelis, et al. [39] proposed a real options model as a means of valuing non-monetizable benefits under competitive prototyping. And Arnold and Vassilou [40] showed how the theory can be applied to estimate the benefits (from a contractor's perspective) of increased revenue stability under a multi-year procurement, in comparison to a series of single-year procurements.

Of particular interest to this research project, McGrath and Prather [5] showed in 2016 how real options theory can be applied to make decisions on the acquisition of technical data to support the competitive procurement of spare parts. In that paper, the authors used real options theory to account for the uncertainty in need associated with the purchase of the parts, as well as the variability of the cost to acquire them. Defining a technical data option as the right to acquire the TDP and deliverables in the future, at a fixed price, McGrath and Prather were able to calculate the value of that option at various stages in the program life cycle, based on the estimated benefit of avoiding costs that would be incurred if the TDP were not available. To implement these calculations, the authors developed a dynamic programming tool that computed the value of data options for competitive spares procurement.

Research Method

This research project sought to extend the 2016 work of McGrath and Prather [5] by evaluating the feasibility of the approach they outlined, in the context of DoD acquisition business practices. A key objective was to show how whether and how real options theory represents a general approach to technical data valuation under conditions of uncertainty—not just for the competitive procurement of spare parts, but for a wide range of practical applications.

To achieve this objective, the authors initially proposed a case-study approach, with four research tasks:

- **Literature review**. The scope of this review included procedures for determining data needs, resolving conflicting assertions in data rights, and defining requirements for technical data delivery. It also included discussions with acquisition professionals concerning contracting methods, other applications of the real options approach, and obstacles to practical implementation.
- **Application**. This task sought to enhance the dynamic programming tool to cover the technical data needs identified in the program selected for case study. The enhanced tool would then be used to compare an alternative acquisition approach to the approach actually used in the case-study program.
- **Case Study Development**. In this task, the results of the previous task were to be formalized as a case study, including comparison of projected differences in life cycle costs, identification of key factors underlying the differences, face validation of the exercise, and development of an instructional aid or casebook.
- **Documentation**. This task included preparation of interim and final reports.

An important interim finding, discussed below under Analysis and Results, was that neither the program initially envisioned for the case study nor the other programs contacted during the course of this research found themselves in a position to provide the necessary information for case study purposes. Accordingly, the research method was adjusted as follows:

- **Application**. Instead of enhancing the dynamic programming tool based on the needs of a particular program, the research aimed at the broadest possible generalization. In other words, the research sought to anticipate questions that might arise under many different classes of acquisition programs, different types of systems, different uses of technical data, and so forth—and to restructure the tool in a way that would accommodate all of them. To demonstrate the versatility of the generalized model, this task would then apply it to a use case other than the spare parts example used by McGrath and Prather [5].

- **Case Study Development**. In lieu of a case study, the research aimed to identify the reasons behind the unavailability of the supporting data; to identify conditions, practices, and/or business models that might make those data available; and to identify the implications for DoD acquisition policy and practice. These efforts culminated in an alternate task,
- **Business Practice Development**. In this task, a framework was developed for considering risks and price negotiation considerations from both contractor and DoD viewpoints that would support contracting for options for delivery of TDSs.

The following section presents the results of this adjusted method.

Analysis and Results

The Generalized Dynamic Programming Model

The process of generalization focused on three aspects of the model: the range of needs / use-cases addressed, the types of costs included, and the logical relationships between and among different data acquisition paradigms.

With respect to needs / use cases, the tool developed by McGrath and Prather [5] focused on the competitive procurement of spare parts. For the widest possible generalization, it is necessary to re-cast both the terminology and the underlying meaning of the model variables. For example, one of the key terms in the earlier model is a “net cost avoidance,” based in part on the difference between the cost of procuring spares competitively and non-competitively. In the generalized version, these two quantities represent one particular example of a more general notion: the difference between the cost of resolving a need with and without access to a particular subset of the TDP. Moreover, instead of comparing these two strategies head-to-head (by computing a net difference), the generalized model tracks the costs separately, as one or the other is incurred under an annual sequence of choices. This allows the comparison of more than two approaches.

Second, the generalized model includes the annual cost of maintaining a technical data option, which was not included in the earlier model.

Third, the structure of the generalized model accommodates different logical assumptions and dependences. For example, it is possible to differentiate between an option that is priced on the assumption that it may or may not be exercised at a given point in the future, versus one for which a future commitment is made in advance. (Using the terminology of real options theory, it accommodates a mixture of European-style and American-style options.) This allows the user to evaluate the effects of discount pricing for early decision making. A second example (not illustrated in this paper) is the ability to specify that some courses of action can only be chosen early in the program’s life cycle—within the first five years, for example.

The following paragraphs show the results of this generalization process by tracing the steps that lead to the general formulation.

Given a stated need/use case for technical data (for example, the desire to use data for depot-level repair), a TDS that meets this need, and a time frame of interest (year *y* = 1, … *Y*), define the following variables:

P_y *the* ***P****robability that the need for the data will exist in year y*

O_y *the cost of maintaining the* ***O****ption to acquire the data in year y (for example, the annual cost of subscribing to a contractor's PLM system)*

A_{By} *the cost to* ***A****cquire the data by* ***B****uying it in year y*

A_{Ly} *the cost to* ***A****cquire the data by* ***L****easing it in year y*

A_{Wy} *the cost to* ***A****cquire surrogate data in year y via* ***W****orkaround; that is, acquiring an equivalent capability with respect to the need without accessing the particular TDS in question (for example, through reverse engineering)*

S_Dy the cost of Satisfying the need in year y,assuming access to the necessary Data either the TDS in question or surrogate data (for example,the cost of providing organic depot"-" level maintenance,given that one has access to the necessary data)

S_{Ny} *the cost of* ***S****atisfying the need in year y, assuming* ***N****o access to data (for example, by purchasing depot-maintenance services from the contractor who holds the necessary data)*

Suppose the data have not been purchased as of year *y*. Then the DoD PM has six choices:

1. Exercise the option by buying the TDS in year *y*, irrespective of prior knowledge of need
2. Exercise the option by leasing the TDS for use during year *y*, irrespective of prior knowledge of need; maintain the option for future years (e.g., by continuing a PLM subscription)
3. Exercise the option by buying the TDS in year *y* if needed; otherwise, maintain the option for future years
4. Exercise the option by leasing the TDS for use during year *y*, if needed; maintain the option for future years
5. Forego the option and acquire data via workaround if needed
6. Forego the option and, if necessary, attempt to meet the need without access to the data

Note that current practice—purchasing the entire TDP up front—can be viewed as making choice 1 in year 1 … with respect to the entire TDP, not simply this TDS. Admittedly, there is a nuance here regarding the definition of "year 1," since current regulations allow for deferred ordering and/or delivery [41]. However, the above framework easily accommodates any such arrangement (since one can opt for choice 1 in any year *y*).

Only "sensible" choices are included in the above list: for example, the choice "acquire data via workaround irrespective of need" does not appear, because it is difficult to imagine the circumstances that would cause a PM to use extraordinary means such as reverse engineering in the absence of a clear need to do so.

At first glance, it appears that choices 1 and 2 are always dominated by choices 3 and 4, respectively, which are similar but avoid incurring costs in the absence of need. However, choices 1 and 2 might become attractive if a contractor were to offer a discount based on an early Government commitment to a future buy or series of lease decisions. (In such a case, the values of A_{By} and A_{Ly} would depend on the choice made.)

Some of the above choices, when selected in a given year, limit the choices available in subsequent years. For example, once the data are purchased, choices 1, 2, 3 and 5 are obviated: the only remaining choice is whether to maintain the option for subsequent access. (In practice, this question corresponds to the decision whether to pay the contractor to continue to maintain and update the data, or whether to take on those responsibilities by transferring the data to a Government PLM system. The tradeoffs involved in that decision are beyond the scope of this paper. Here, it is simply assumed that there are no further data costs once the TDS has been purchased—an important caveat that should be kept in mind when assessing the results of these computations.)

The surrogate data set produced by implementing the "workaround" is assumed to be completely equivalent to the subject TDS and fully adequate to the need in question; thus, a decision to implement the workaround also results in no further costs for data.

Finally, data options are considered to be defined and negotiated up front; in other words, they can be maintained, but not created during the out-years. Thus, if choice 5 or 6 is made in any given year, choices 1 through 4 become unavailable thereafter.

Begin by considering year *Y*, the final year of the planned life cycle, under the assumption that all choices are available in that year. The total costs incurred under choice *i* in year *Y* are designated $\Gamma_{i,Y}$ and calculated as follows.

$$\Gamma_{1,Y} = A_{BY} + (P_Y\, S_{DY})$$

$$\Gamma_{2,Y} = A_{LY} + (P_Y\, S_{DY})$$

$$\Gamma_{3,Y} = P_Y\, (A_{BY} + S_{DY})$$

$$\Gamma_{4,Y} = P_y\, (A_{LY} + S_{DY})$$

$$\Gamma_{5,Y} = P_y\, (A_{WY} + S_{DY})$$

$$\Gamma_{6,Y} = P_Y\, S_{NY}$$

Now consider the total cost from year *Y-1* through year *Y*, assuming that choice *i* is made in year *Y-1*. This cost is denoted as $\Gamma_{i,Y-1:Y}$.

The costs for year *Y-1* are found by substituting *Y-1* for *Y* in the above expressions. Regarding costs in year *Y*, it is possible, as discussed above, that some choices for that year will be limited by the choices made in year *Y-1*. If the data will definitely be bought in year *Y-1* (as is true under the case $\Gamma_{1,Y-1:Y}$), then the only cost incurred in year *Y* will be the cost of satisfying the need (if it exists), given that the data are available: that is, $P_Y * S_{DY}$. If, however, the data are not purchased in year *Y-1* (for example, under the case $\Gamma_{2,Y-1:Y}$), then all choices are available in year *Y*—provided the option to access the TDS is maintained (at cost O_{Y-1}). It seems reasonable to assume that a prudent PM would make the "best" choice for year *Y*; i.e., the one that minimizes the cost. Therefore the year *Y* cost in this case is taken as the minimum over all *i* = 1, … 6 of $\Gamma_{i,Y}$.

For some cases, the logic is more complicated. For example, under the case $\Gamma_{3,Y\text{-}1:Y}$, the TDS is purchased only if the need occurs; therefore, the option is maintained only if it does not: that is, rather than the term $O_{Y\text{-}1}$, we have $(1\text{-}P_{Y\text{-}1})O_{Y\text{-}1}$. Regarding costs in year Y, the need will be satisfied with cost S_{DY} if the TDS has been previously purchased ($P_{Y\text{-}1}$) and the need arises (P_Y). If the data were not purchased in the preceding year (1 - $P_{Y\text{-}1}$), the PM will make the best (lowest cost) choice for year Y.

Applying similar logic to the other cases yields the following results:

$$\Gamma_{1,Y\text{-}1:Y} = A_{BY\text{-}1} + (P_{Y\text{-}1}\, S_{DY\text{-}1}) + (P_Y\, S_{DY})$$

$$\Gamma_{2,Y\text{-}1:Y} = A_{LY\text{-}1} + (P_{Y\text{-}1}\, S_{DY\text{-}1}) + O_{Y\text{-}1} + \min_{i=1\ldots6} \Gamma_{i,Y}$$

$$\Gamma_{3,Y\text{-}1:Y} = P_{Y\text{-}1}\,(A_{BY\text{-}1} + S_{DY\text{-}1}) + (1 - P_{Y\text{-}1})O_{Y\text{-}1} + P_{Y\text{-}1}(P_Y S_{DY}) + (1 - P_{Y\text{-}1}) \min_{i=1\ldots6} \Gamma_{i,Y}$$

$$\Gamma_{4,Y\text{-}1:Y} = P_{Y\text{-}1}\,(A_{LY\text{-}1} + S_{DY\text{-}1}) + O_{Y\text{-}1} + \min_{i=1\ldots6} \Gamma_{i,Y}$$

$$\Gamma_{5,Y\text{-}1:Y} = P_{Y\text{-}1}\,(A_{WY-1} + S_{DY-1}) + P_{Y\text{-}1}(P_Y S_{DY}) + (1 - P_{Y\text{-}1}) \min_{i=5,6} \Gamma_{i,Y}$$

$$\Gamma_{6,Y\text{-}1:Y} = P_{Y\text{-}1}\, S_{NY\text{-}1} + \min_{i=5,6} \Gamma_{i,Y}$$

This scheme can now be extended recursively, backwards through year 1. To do so, note that $\Gamma_{i,Y}$ can also be written as $\Gamma_{i,Y:Y}$: that is, with respect to the particular year *Y-1*, the cost for the next year ($\Gamma_{i,Y}$) is the same thing as the cost for the next year through the end of the life-cycle ($\Gamma_{i,Y:Y}$). With respect to *any* given year *y-1*, the best (lowest-cost) choice for the next year is the one that minimizes the total cost for the next year (*y*) through the end of the life-cycle (*Y*). Thus, given that the value of $\Gamma_{i,y:Y}$ is known for any $y < Y$, then the value for the previous year *y-1* is given by

$$\Gamma_{1,y\text{-}1:Y} = A_{By\text{-}1} + \left(P_{y\text{-}1}\, S_{Dy\text{-}1}\right) + \sum_{j=y}^{Y} (P_j S_{Dj})$$

$$\Gamma_{2,y\text{-}1:Y} = A_{Ly\text{-}1} + (P_{y\text{-}1}\, S_{Dy\text{-}1}) + O_{y\text{-}1} + \min_{i=1\ldots6} \Gamma_{i,y:Y}$$

$$\Gamma_{3,y\text{-}1:Y} = P_{y\text{-}1}\,(A_{By\text{-}1} + S_{Dy\text{-}1}) + (1 - P_{y\text{-}1})O_{y\text{-}1} + \sum_{j=y}^{Y} P_{y\text{-}1}(P_j S_{Dj}) + (1 - P_{y\text{-}1}) \min_{i=1\ldots6} \Gamma_{i,y:Y}$$

$$\Gamma_{4,y\text{-}1:Y} = P_{y\text{-}1}\,(A_{Ly\text{-}1} + S_{Dy\text{-}1}) + O_{y\text{-}1} + \min_{i=1\ldots6} \Gamma_{i,y:Y}$$

$$\Gamma_{5,y\text{-}1:Y} = P_{y\text{-}1}\,(A_{Wy-1} + S_{Dy-1}) + \sum_{j=y}^{Y} P_{y\text{-}1}(P_j S_{Dj}) + (1 - P_{y\text{-}1}) \min_{i=5,6} \Gamma_{i,y:Y}$$

$$\Gamma_{6,y\text{-}1:Y} = P_{y\text{-}1}\, S_{Ny\text{-}1} + \min_{i=5,6} \Gamma_{i,y:Y}$$

The resulting values of $\Gamma_{i,y:Y}$ define the cost of making choice *i* in year *y*, where that cost of that choice is defined as the total expected value of future costs incurred in satisfying the underlying need for the data, over the years *y* through *Y* (i.e., costs over the remainder of the life-cycle).

Application of the Generalized Model

The calculated values of $\Gamma_{i,y:Y}$ can be used to answer practical questions faced by DoD acquisition PMs. A few of these are listed below.

Question: for a given technical data need (use-case), suppose the contractor proposes to make the corresponding TDS available for immediate purchase at a stated price (A_{B1}). Should the program immediately acquire the technical data at this price, without planning on other arrangements to satisfy the need?

Answer: this question simply asks whether the decision in year 1 should be choice 1, versus choices 5 and 6 (since no arrangements that include options, data leasing, PLM subscriptions, etc. have been proposed). To answer this question, the PM would estimate the probability of need (P_y), the cost of acquiring the data by other means (W_y), and the cost of satisfying the need with (S_{Dy}) and without (S_{Ny}) access to the data. If

$$\min_{i=5,6} \Gamma_{i,1:Y} - \Gamma_{1,1:Y} > 0$$

then the Government may wish to consider purchasing the data at this price. Note that this calculation does not include the cost to the Government of maintaining the data, which should also be a factor in this decision. If the analysis suggests that the need is highly uncertain, the Government may wish to investigate an arrangement that involves technical data options.

Question: for a given need (use-case), suppose the contractor proposes to make data available for future use by defining an annual PLM subscription price (*Oy*), along with proposed costs for purchase (A_{By}) or lease (A_{Ly}) of the corresponding TDS. Does the proposed arrangement represent a good value for the Government?

Answer: again, this question corresponds to a decision in year 1, where the choice is between those cases that include the proposed arrangement (choices 2 through 4) and those that do not (choices 1, 5, and 6). Therefore, if

$$\min_{i=1,5,6} \Gamma_{i,1:Y} - \min_{i=2\ldots4} \Gamma_{i,1:Y} > 0$$

then the proposed agreement can be expected to yield net cost savings, and the arrangement represents a good value for the Government.

Question: if the Government chooses to enter into an arrangement for future buy or lease of technical data, how long, for planning purposes, the PM assume the subscription to the contractor's PLM will be maintained?

Answer: this question asks for how many years will it remain true that choices in which the subscription is maintained (choices 2, 3, and 4) are lower-cost choices than those that do not (choice 1). In other words, find the lowest value of *y* (call it $\tilde{y}$) such that

$$\min_{i=2,3,4} \Gamma_{i,\tilde{y}:Y} - \min_{i=1} \Gamma_{1,\tilde{y}:Y} > 0$$

For planning purposes, the PM should assume the subscription is maintained for at least $\tilde{y}$ years—and that the Government may need to make arrangements to maintain the data after that time. Note that this conclusion is based on the information available at the time of decision (year 1). In practice, it may be advisable to update this information for future decision making purposes. In other words, at some future year year $\bar{y}$, the PM might update the estimated values of $(P_{\bar{y}}, P_{\bar{y}+1}, \ldots P_Y)$, $(A_{W\bar{y}}, A_{W\bar{y}+1}, \ldots A_{WY})$, $(S_{N\bar{y}}, S_{N\bar{y}+1}, \ldots S_{NY})$, and other variables as appropriate, before deciding how to proceed for the remainder of the planned life-cycle (year $\bar{y}$ through year *Y*).

Application of the Generalized Model: An Example

To illustrate, consider a case quite different from the spare-parts example analyzed in McGrath and Prather [5]. Here, the system in question is a small fleet of vehicles that are being acquired and modified for a special-purpose mission. The vehicles have an expected service life of 20 years. The Government desires to use data for depot-level repair, which will be provided organically through an existing depot that also services other variants of the basic vehicle.

Depot-level maintenance comprises scheduled and un-scheduled repair and/or overhaul. The normal maintenance cycle calls for a depot-level overhaul once every eight years. Since the total number of vehicles is small, half the fleet will undergo their first scheduled overhaul in year 8 and the remaining half will begin their cycle at year 9. Starting in year 4, there is a 10 percent probability that at least one vehicle will require un-scheduled repairs in a given year; when that occurs its maintenance cycle is re-set. After year 9, the chances of requiring the data in one of the "off" years will gradually increase (due to the random nature of the unscheduled repairs) and the chances of requiring the data in one of the initially scheduled years will decrease—albeit at a much slower rate. The resulting estimate of *Py* is as follows.

y	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
P_y	0.00	0.00	0.00	0.10	0.10	0.10	0.10	1.00	1.00	0.20	0.20	0.20	0.30	0.30	0.30	0.95	0.95	0.40	0.40	0.40

The contractor defines a TDS for this use-case. To maintain the option of accessing the TDS at a future date, the contractor proposes to charge an annual PLM subscription fee of $2,000. The cost of buying the data is quoted at $85,000 if the TDS is purchased within years 1 through 10; this cost decreases to $35,000 in years 11 through 20, as the system approaches the end of its planned service life. The cost of leasing the TDS for any one year is quoted at $10,000.

The Government estimates that the cost of depot-level maintenance, under the planned maintenance concept, is approximately $950,000 in each of the scheduled years. The comparable cost, under a contractor logistics support (CLS) arrangement, is estimated at $1,400,000 per year, since the contractor is not able to spread some of the costs across other vehicle variants, as the Government is. (Note: in reality, this arrangement would probably be available only if it were chosen within the first few years, since the cost of constituting a CLS program downstream would likely be prohibitive. These dynamics can be accommodated within the modeling framework by making some adjustments to the preceding formulas; for simplicity, those details are not included in this paper.)

If the Government did not have access to the TDS and wished to provide this support organically, it would have to reverse-engineer the system: the one-time cost is estimated at one-fourth the non-recurring cost of acquiring the modified vehicle, or $9,500,000.

In thousands of dollars ($K), the model inputs have the following values.

P_y $as\ defined\ above$

$O_y \ = 2$

$A_{By} \ = 85, for\ 1 \ \leq y \ \leq 10;\ \ 35, for\ 11 \ \leq y \ \leq 20$

$A_{Ly} \ = 10$

$A_{Wy} \ = 9{,}500$

$S_{Dy} \ = 950$

$S_{Ny} \ = 1{,}400$

The computed values of $\Gamma_{i,y:Y}$ in this case are as follows.

y	1	2	3	4	5	6	7	8	9	10
$\Gamma_{1,y:20}$	$6,737	$6,737	$6,737	$6,737	$6,642	$6,547	$6,452	$6,357	$5,407	$4,457
$\Gamma_{2,y:20}$	$6,743	$6,741	$6,739	$6,736	$6,638	$6,540	$6,442	$6,335	$5,373	$4,419
$\Gamma_{3,y:20}$	$6,733	$6,731	$6,729	$6,727	$6,629	$6,532	$6,434	$6,355	$5,405	$4,418
$\Gamma_{4,y:20}$	$6,733	$6,731	$6,729	$6,727	$6,629	$6,531	$6,433	$6,335	$5,373	$4,411
$\Gamma_{5,y:20}$	$16,450	$16,450	$16,450	$16,950	$16,719	$16,489	$16,258	$21,090	$19,190	$12,034
$\Gamma_{6,y:20}$	$9,800	$9,800	$9,800	$9,800	$9,660	$9,520	$9,380	$9,240	$7,840	$6,440

y	11	12	13	14	15	16	17	18	19	20
$\Gamma_{1,y:20}$	$4,217	$4,027	$3,837	$3,552	$3,267	$2,982	$2,080	$1,177	$797	$417
$\Gamma_{2,y:20}$	$4,229	$4,039	$3,849	$3,564	$3,279	$2,987	$2,073	$1,164	$778	$392
$\Gamma_{3,y:20}$	$4,218	$7,068	$6,298	$5,814	$5,329	$3,082	$2,134	$1,618	$779	$395
$\Gamma_{4,y:20}$	$4,221	$4,031	$3,842	$3,557	$3,272	$2,986	$2,072	$1,158	$772	$386
$\Gamma_{5,y:20}$	$11,582	$11,130	$11,331	$10,666	$10,002	$14,061	$12,235	$5,916	$5,048	$4,180
$\Gamma_{6,y:20}$	$6,160	$5,880	$5,600	$5,180	$4,760	$4,340	$3,010	$1,680	$1,120	$560

Question: Is the proposed arrangement a good deal for the Government?

Answer: we have

$$\min_{i=1,5,6} \Gamma_{i,1:20} - \min_{i=2\ldots4} \Gamma_{i,1:20} \cong 0$$

The Government may wish to consider purchasing the data outright, but only if it can be maintained and updated at zero cost, since $\Gamma_{1,1:20}$ is approximately equal to $\Gamma_{i,1:20}$, *i* = 2, 3, 4. The terms of the proposed agreement appear favorable from the Government perspective—particularly in comparison with the alternatives of obtaining data through reverse engineering ($\Gamma_{5,1:20}$) or purchasing depot-level maintenance services via CLS ($\Gamma_{6,1:20}$), where a savings of between $3.1 and $9.7 million over the lifetime of the system is possible.

Question: for how long, for planning purposes, should the PM assume the subscription to the contractor's PLM will be maintained?

Answer: there is no "crossover" value $\tilde{y}$: for planning purposes, the PM should assume the subscription is maintained for the full 20 years. Year 10, following the completing of the first round of scheduled overhauls, may be a good place to revisit this conclusion by updating the estimated values of P_y, A_{Wy}, S_{Dy}, and S_{Ny} for the second ten years of the planned life-cycle.

Case Study Development

Personnel contacted during the case study phase of the research effort (approximately June 2017 through December 2018) included senior acquisition executives, personnel from service research laboratories, and OSD proponents of the DES. These individuals were enthusiastic about the prospect of a valuation method that would allow PMs to price options for access to and/or ownership of appropriate technical data at the time of need. Based on these discussions, three candidate programs were identified, based on current acquisition phase (programs that had entered EMD were judged most likely to have available information regarding proposed prices and actual costs for data) and potential openness to new methods of acquiring technical data (for example, their embodiment of the model-analyze-build principles of the DES). These three programs (one each from the U.S. Army, Navy, and Air Force) ranged in size from ACAT I through ACAT III.

Unfortunately, follow-on discussions with individuals at the respective program offices (including both Government and contractor support personnel) disclosed that none of them were able to supply the information needed to support the development of a case study for this research project. In brief, the underlying reason was that the use-case information necessary to populate the model had not been required to support prior program decision making—notwithstanding the current requirement for a product support BCA—hence, it had not been developed. To develop that information now would require additional time and resources, which program offices were not in a position to provide.

Thus, as long as DoD methods for technical data valuation do not explicitly address uncertainty, there is no impetus for PMs to develop the data that would demonstrate the efficacy of new methods that do so. It appears that this paradox can only be resolved under the auspices of a DoD-sanctioned (and resourced) pilot program undertaken for that purpose.

Such an opportunity may be very near on the horizon. As part of the November 2018 report of the Section 813 Panel [22], White Paper 4 recommends a pilot program to assess alternative means of IP valuation. The generalized model described earlier in this paper could be included among the alternatives considered.

Framework for an Alternative Business Model: TDaaS

To help create conditions under which a DoD pilot project could successfully evaluate the real options approach to technical data acquisition and pricing, this research project concluded by developing a business model that corresponds to that approach. The business model is denoted "Technical Data as a Service (TDaaS)."

The TDaaS business model is best understood by contrasting it to the current business model, depicted in Figure 1. In the current model, the contractor formulates a TDP for the system being acquired and assesses its value based on its anticipated market worth, the cost required to develop and maintain it, and the income that could be realized through owning it. Because DoD policy requires the Government PM to consider procuring the TDP, the contractor prepares a quote. The potential uses of the TDP—and the attendant risks of disclosure—are not well understood; therefore, the contractor assumes the worst and adjusts the quoted TDP price upward accordingly. The DoD PM conducts a product support BCA; however, the BCA does not explicitly address uncertainty regarding the need for technical data. Uncertainty regarding the data requirement is not quantitatively factored into the Government's evaluation of the quoted price, nor does the Government consider options for buying or leasing the TDP—or any subset of the TDP—at the time of need. The only option considered is whether or not to acquire the entire TDP at the quoted price, based on whatever needs are identified in the BCA or are defined in DIDs and CDRLs. Because the value of the TDP to the Government is unknown, the DoD PM is unable to assess the quoted price objectively and instead makes the determination by reviewing the supporting data and considering prices paid for other TDPs.

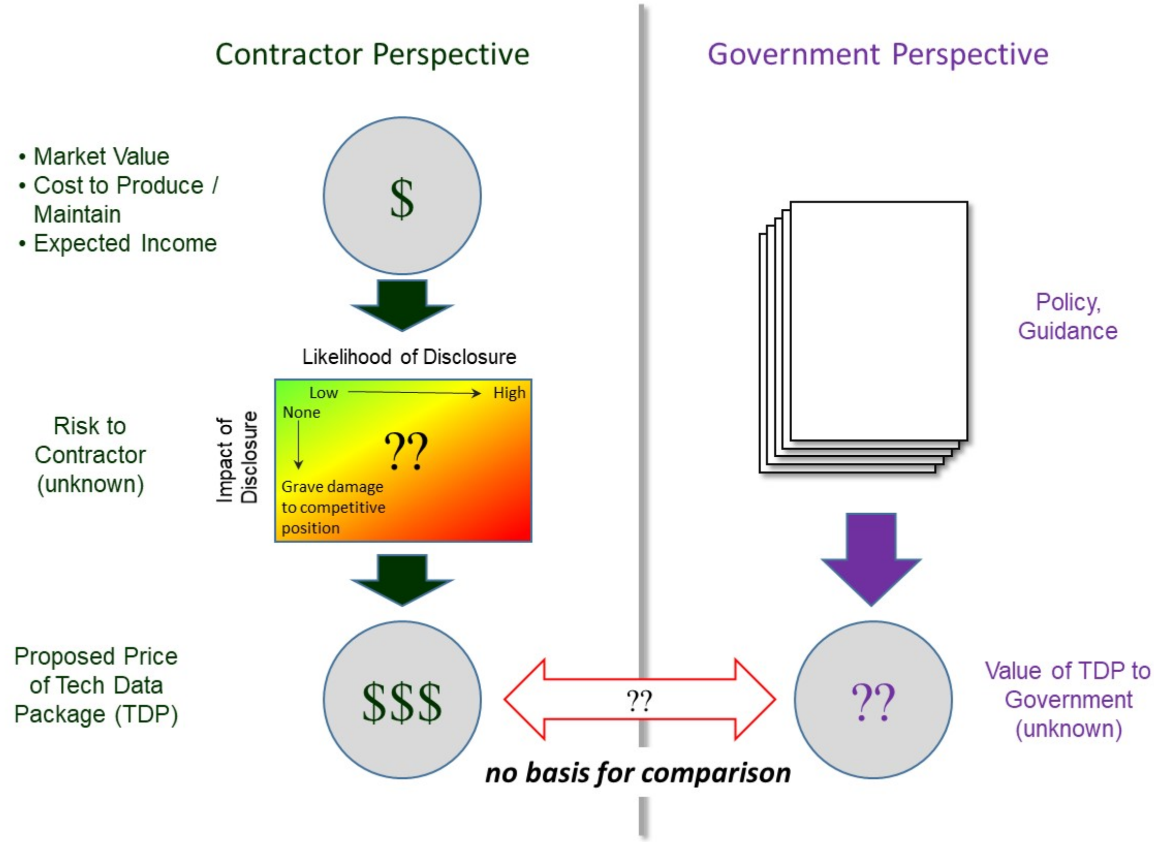

Figure 1: Current Business Model

In the TDaaS business model, the central feature is the Government's development of multiple use cases: sequences of events that describe one or more circumstances under which access to technical data would be needed, along with the activities that would likely occur with and without access to such data. Based on these use cases, the contractor prepares a corresponding ensemble of TDP subsets—TDSs—and assesses the disclosure risks, based on the category into which each use case falls (e.g., training, field maintenance, depot maintenance, and so on). Risks will tend to be circumscribed according to use case category. For example, if the Government's use is limited to the production of technical publications, it is reasonable for the contractor to assess the risk of disclosure as low, based on the assumption that access to those publications can be controlled. By contrast, a stated intent to use technical data for the fabrication of spare parts by third-party suppliers necessarily involves greater disclosure and greater risk. The

DoD PM incorporates these use cases into the product support BCA—and in the process develops the cost inputs for the generalized valuation model described in this paper. The BCA considers the value to the Government of having the option, at any point in the product life cycle, to acquire the data—either by leasing it for one-time use or by purchasing it for delivery to a Government PLM system. Because the BCA assess the value of the data from the Government's perspective, the DoD PM is able to determine whether or not the quoted prices (including option prices) for individual TDSs represent a good deal for the Government, and to negotiate accordingly. If the decision is made to acquire options for downstream data access, the Government purchases a renewable subscription to the contractor's PLM system. During the sustainment phase of the system's life cycle, the PM makes case-by-case decisions whether to exercise a pre-negotiated option for lease or purchase of one or more TDSs.

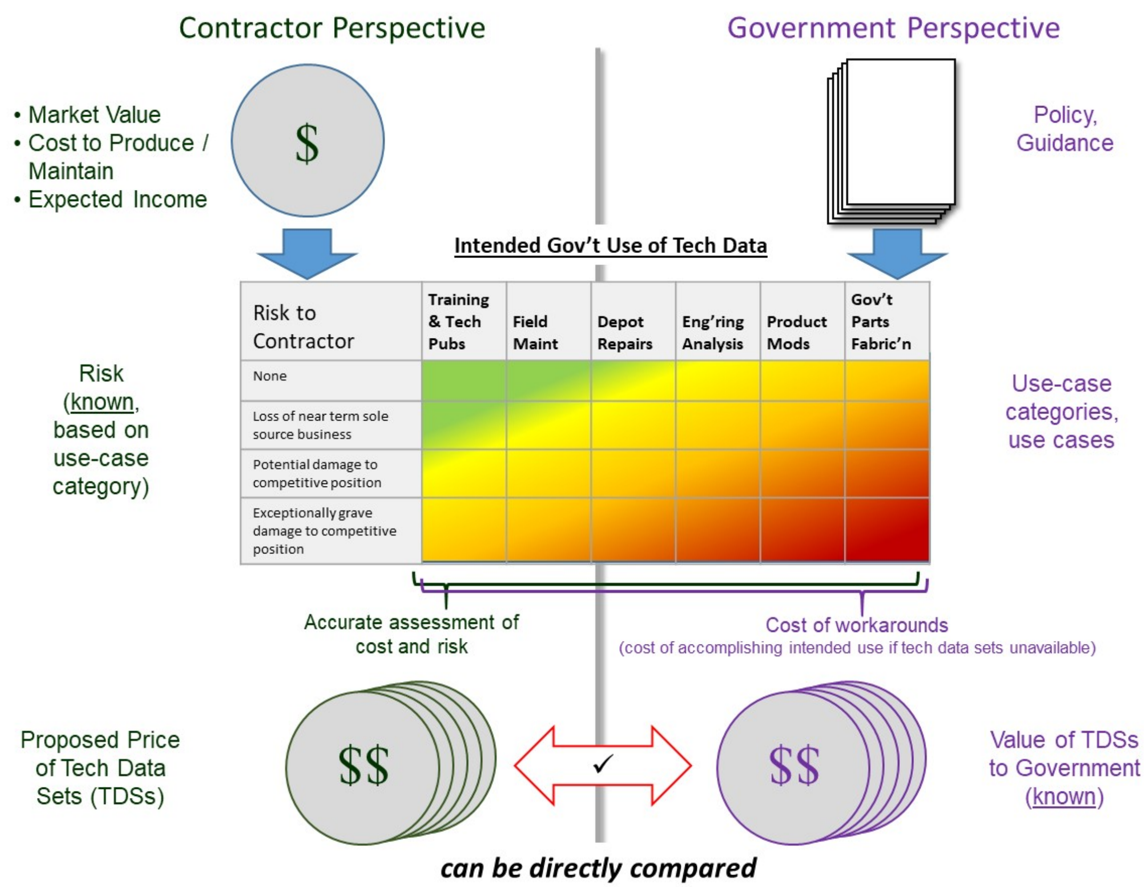

Figure 2: TDaaS Business Model

If a need arises that does not correspond to or fall within a pre-negotiated use case and TDS option, the Government documents the need and asks the contractor to define an appropriate new TDS. The price for such a TDS can be determined in one of two ways. One is to determine its value to the Government by performing the same type of analysis that was done in the original product support BCA, using values of the generalized model inputs that are current as of the time of the newly-identified need and negotiating the price in what is now a sole-source environment. The second approach is to use a pricing schedule, applying pre-negotiated factors corresponding to the applicable use case category. Those factors would have been developed up front, using both industry risk assessment and the generalized model to arrive at a range of prices that are acceptable from both Government and contractor perspectives. In principle, the use of pre-negotiated schedules for technical data pricing has certain similarities to the use of Federal Supply/Service Schedule (FSS) contracts. In FSS contracts, supplies or services are grouped by Special Item Numbers, or SINs (analogous to use case categories) and provisions are made for discounts, modifications, and other adjustments. The ordering process includes determining the appropriate SIN(s) and applying one or more parameters—usually, quantity (of supplies or labor hours)—to the pre-negotiated unit price(s) under the schedule agreement. For a technical data pricing schedule, the ordering parameter will not be quantity: pricing may instead be calculated by determining (1) which Government use case category is the most applicable and 2) which category of data rights risk to the contractor the TDS content falls in. (There may also be charges for translating and delivering the TDS in the required format.) This approach will require some care in the selection and definition of the use case categories on which the schedule is based.

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Conclusions and Recommendations

Using real options theory can help realize the USDRE's goal of "mov[ing] toward a model that allows for negotiating options for access to IP during competition, then exercising those options as needs are realized" [11]. Specifically, the valuation approach, generalized dynamic programming model, and framework for a TDaaS business model developed and presented in this paper represent a powerful combination that offers many benefits:

First, it helps DoD to avoid purchasing data that are not needed. By acquiring only the data that are needed, when they are needed, and for how long, the Department can realize significant savings in system life-cycle costs.

Second, it allows DoD PMs to respond to unanticipated needs by preserving options for future data access and/or ownership.

Third, it helps industry and Government arrive at a fair and reasonable price for technical data. The DoD can assess the value of the data from its own perspective; industry can more accurately determine the risks of data disclosure and spread those risks over smaller data subsets. The net result is a potential lowering of technical data costs to DoD.

Fourth, it is consistent with, and helps to achieve the benefits of, the DoD's digital thread concept and its new systems engineering strategy. These indirect benefits include not only acquisition program cost savings but also improved trade space exploration and reduced acquisition cycle time [42].

Demonstrating the magnitude of these benefits via case-study analysis will be difficult, if not impossible, unless one or more PMs is directed—and possibly resourced—to develop the necessary supporting information. There is currently no impetus for the PM to do so: this information is not currently required as part of the product support BCA, and it is not considered in current cost and pricing analyses that inform negotiations for technical data acquisition. The resulting inertia can best be overcome under the auspices of a DoD-directed pilot program.

As a result of the November 2018 report of the Section 813 Panel [22], the DoD may soon be undertaking one or more pilot programs to assess alternative means of IP valuation. Accordingly, the authors recommend that the results of this research be incorporated into those efforts.

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