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Application of Acquisition Theory

by

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Contents

Abstract

This paper reports on a research project that aims to reduce the cost of government-led aerospace system development projects while accelerating schedules and improving performance. The incentives produced by standard requirements-based contracting lead to sub-optimal outcomes from the perspective of the government. We create a contract that incentivizes optimization rather than using requirements. The incentives align cost savings, rapid development, and higher quality with contractor profit. The contractor is paid more for a product with higher performance, and even more for a product that is delivered sooner. Therefore, the contractor can balance cost, performance and time in the way that the government would prefer. Superior program outcomes arise naturally from the incentives in the contract.

1 Introduction

It is no secret that government-led aerospace projects suffer from widespread cost overruns, schedule overruns, and sub-optimal quality. Previous research suggests that these issues may partially stem from a much broader problem: the intrinsic misalignment of incentives present in a standard requirements-based engineering contract. However, there is an alternative: value-driven design. In this paper, we seek to build upon previous research by showing what this concept may look like in the context of a broadcast satellite.

1.1 Terminology

For the purposes of this paper:

- *Benefit* refers to the anticipated value that will be gained from a product. In general, this is the probabilistic expectation of net present value. Benefit includes operation, maintenance and support costs, but excludes engineering costs, manufacturing costs, and purchase price, which are all considered separately.
- *Engineering cost* refers to the total cost expended designing the product. This includes the wages of engineers, the cost of creating prototypes, and operating costs for the department working on the project.
- Manufacturing cost is the cost of manufacturing the product, including all overhead.
- In the case of products intended for use in orbit, *launch cost* refers to the cost associated with launching the product.

1.2 Research Questions

The four overarching questions on which this research is based are as follows.

1. What is the causal relationship among cost reimbursement, award fees, incentives, and project outcomes?
2. How is this relationship affected by the structural complexity and size of the industry engineering organization, including the supply chain?
3. How is this relationship affected by program uncertainty, particularly technical risk?
4. How is this relationship affected by uncertainty in the user environment, that is, by out year changes in the relationship of artifact attributes to government benefit?

This paper will focus primarily on the first of these questions, but will also touch on the second and third.

1.3 Scope

This paper will focus on the application of Acquisition Theory to a model based on the satellite presented in Kannan, Mesmer, and Bloebaum's 2016 paper *Incorporation of Risk Preferences in a Value-Based Systems Engineering Framework for a Satellite System* [1]. It will specifically focus on the development of a broad framework for understanding the incentives at play, while a more detailed analysis of the interactions among individual subsystem designs are reserved for future research.

2 Literature Review

This section will give a brief overview of the relevant research up to this point.

2.1 Principal-Agent Theory

Principal-Agent Theory was developed in 1976 by Michael Jensen and William Meckling [2]. This theory draws from the principles of property rights, agency, and finance and attempts to explain the interactions involved in the relationship between ownership and control over a firm. Specifically, it deals with the ways in which the principal and the agent are conflicted in their interests.

2.2 Value-Based Acquisition

Value-Based Acquisition describes a method of contracting in which the value of a contract is found using an agreed-upon objective function based on the attributes of the design. Paul Collopy has done extensive writing on this topic, including an analysis on the negative impact of direct requirements [3] and evaluations of existing projects through this lens [4]. The objective function in this contract can be used to align the incentives of the government (the Principal) and the contractor (the Agent) from a Principal-Agent Theoretical perspective. The implementation of this idea is one of the primary focuses of our current research.

2.3 The Satellite Model

A 2016 paper by Kannan et al introduced a model of a geo-stationary commercial communications satellite for the purpose of analysis of risk and uncertainty in Value-Based Systems Engineering (VBSE). This model was adapted for use in this paper.

3 Method

Assume a design D is created through an engineering process. Inherent to this design are a given set of attributes, including:

- $A(D)$ - The physical artifact that can be made according to design D
- $B(D) = B[A(D)]$ - the benefit to the government of possessing the artifact A
- $N(D)$ - the engineering cost of D

- $C(D) = C[A(D)]$ - the manufacturing cost of A

For the sake of simplicity, we will treat the artifact A as if it is manufactured instantaneously at the end of the design process. Additionally, we will view the design process as beginning at time 0 and ending at time t. Thus, we can assume that both the manufacturing cost and benefit are incurred at time t.

The engineering cost N will be assumed to be constant throughout the design process, so its center of gravity will be at time $\frac{1}{2}t$.

Because the artifact in question is a satellite, an additional cost variable is required, the launch cost L. We will assume that the launch is scheduled in advance for a time t_L, and that this is when the launch cost is incurred.

We will assume that the preferences of the government and the contractor with respect to time can be defined by the discount factors r_G and r_C, respectively, as follows.

$$r_G = \frac{1}{1 + dr_G} \tag{1}$$

$$r_C = \frac{1}{1 + dr_C} \tag{2}$$

The discount rate dr_G is assumed to be 0.07, and dr_C is assumed to be greater than dr_G. For the purposes of this paper, dr_C will be equal to 0.14.

The most basic scenario is that the government, instead of employing a contractor, designs and builds the artifact themselves. In this case, the value to the government is given below. This equation will be used to gauge government preference in cases involving a contractor.

$$V_G = r_G^t \cdot B - r_G^t \cdot C - r_G^{t/2} \cdot N - r_G^{t_L} \cdot L \tag{3}$$

In the case where the government hires a contractor, the contractor's perception of value will be based on discounted profit. The equation for this is given below for the simplest case, in which the government makes one payment of the amount P to the contractor at time t.

$$V_C = r_C^t \cdot P - r_C^t \cdot C - r_C^{t/2} \cdot N - r_C^{t_L} \cdot L \tag{4}$$

In order to properly align the incentives of the government and the contractor:

$$P = \left(\frac{r_G}{r_C}\right)^t \cdot B - \frac{r_G^t - r_C^t}{r_C^t} \cdot C - \frac{r_G^{t/2} - r_C^{t/2}}{r_C^{t/2}} \cdot N - \frac{r_G^t - r_C^t}{r_C^t} \cdot L + r_C^{-t} \cdot k \tag{5}$$

This equation is constructed such that at any point in the design space, $V_G = V_C$. k is a constant negotiated before the design process begins, in order to make the contract palatable to the contractor.

3.1 The Abstract Satellite

A preliminary abstract model of the Satellite was constructed. The purpose of this was to provide an overview of the problem, and to provide a baseline to which we can compare later results. The model is as follows.

The satellite has three design variables: volume, design time, and number of transceivers. In the code, these are represented by the vector x. However, I will refer to them here as V, t, and n, respectively, for the sake of readability.

The satellite has a density, d, given by the equation

$$d = \frac{1}{2} \cdot d_{water} + e^{-t+8.9094} \tag{6}$$

where d_{water} is the density of water. The surface area of the Satellite is approximated by

$$S_A = 6 \cdot V^{2/3} \tag{7}$$

And the mass is calculated by

$$M = V \cdot d \tag{8}$$

The maximum number of transceivers is a function of the surface area. For the purposes of this paper, we will assume that the number of transceivers will always be equal to the maximum, as this will result in the maximum potential value. Thus,

$$n = n_{max} = S_A \cdot d_{trans} \tag{9}$$

Where d_{trans} is the maximum number of transceivers per unit area.

The benefit to the government is given by the following.

$$B = 10^8 \cdot \left(1 - e^{-0.04 \cdot n}\right) \cdot \left(t^{1/2}\right) \tag{10}$$

There are three primary costs associated with the satellite: engineering cost (N), manufacturing cost (C), and launch cost (L). These are given below, where w is the yearly operating cost of the engineering department.

$$N = w \cdot t + 5000 \cdot n^3 \tag{11}$$

$$C = (-1.3376 \cdot d + 10666.78) \cdot V \tag{12}$$

$$L = 2000 \cdot M \tag{13}$$

3.2 The Detailed Satellite

In the future, a more complete model of the satellite will be used for analysis, with a focus on the preferences of the developers of individual subsystems. The structure of the satellite system is given below.

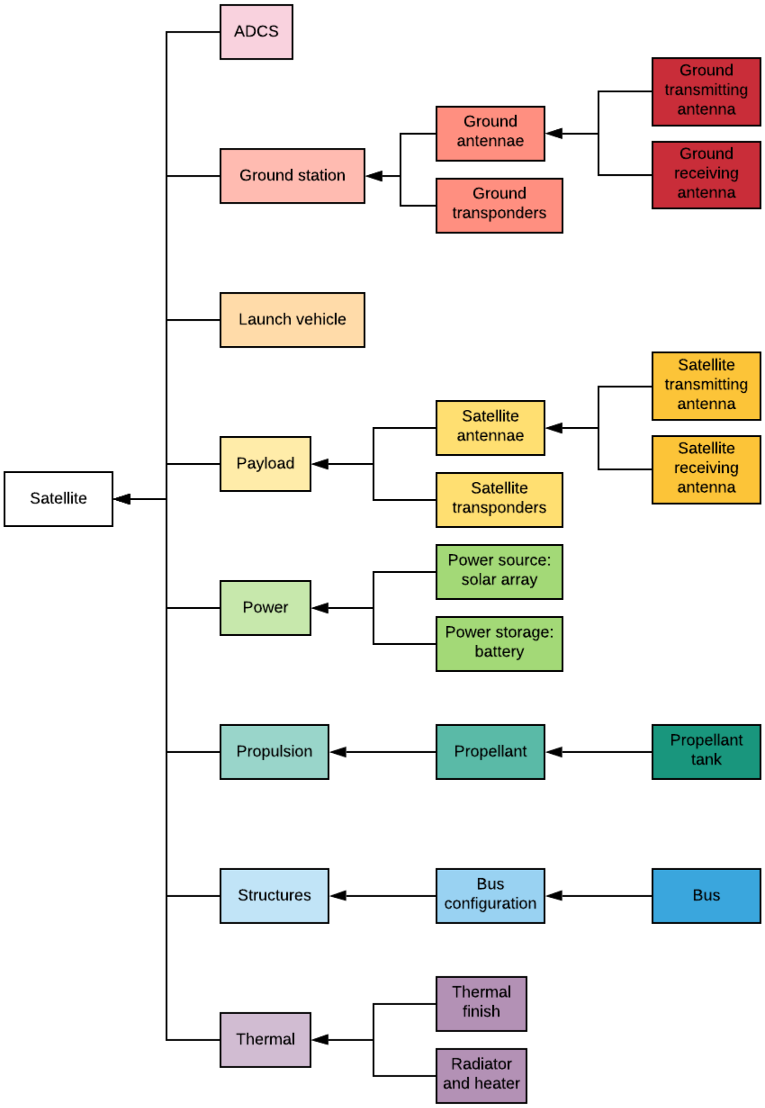

Figure 1: Satellite Structure

4 Results

V_G and V_C were optimized independently using R. The results are given below.

	Volume (m^3)	design time (years)
Government	10.4887	5.0120
Contractor	10.5274	5.7462

Table 1: Optimum satellite design variables

Next, V and t were plotted against the value to the government and to the contractor, while holding the other design variable constant at its optimum.

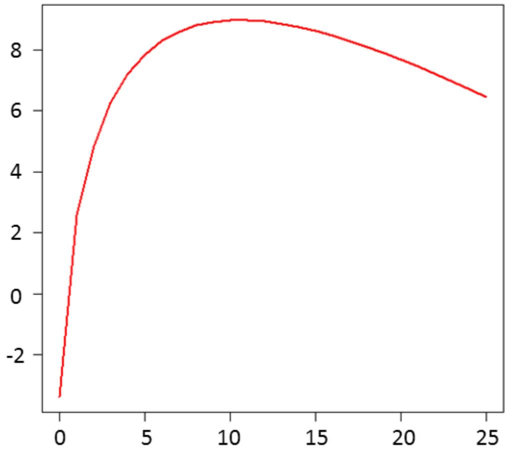

Figure 2: Volume (m^3) vs. value to the government ($10M)

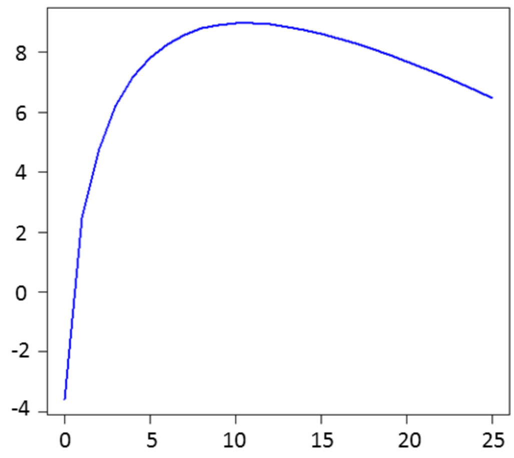

Figure 3: Volume (m^3) vs. value to the contractor ($10M)

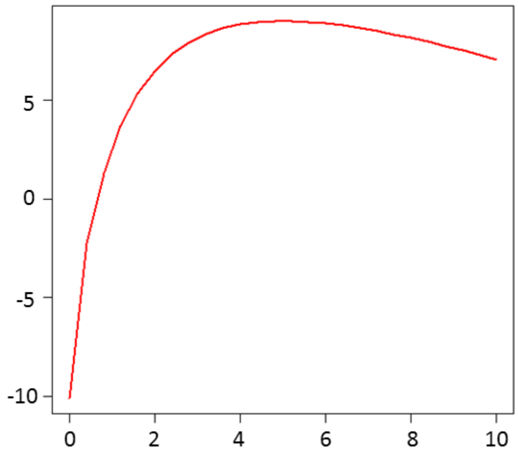

Figure 4: Design time (years) vs. value to the government ($10M)

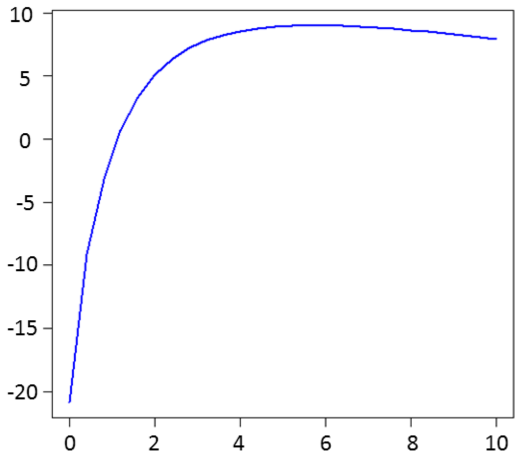

Figure 5: Design time (years) vs. value to the contractor ($10M)

5 Interpretation

Both the design variable graphs and the optimization results show the convergence of the interests of the government and the contractor. This implies that the structure of the contract was successful in aligning the interests of the two parties.

6 Conclusion

There are significant issues in the world of government-led contracts, in the aerospace industry and beyond. However, the success of this contract model in aligning the interests of the government and contractor shows that the future of value-based acquisition is promising, and that it may serve as a viable alternative to our current methods.

Acknowledgments

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