On Coordinating Contracts in Decentralized Sequential Projects

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Most strategic projects today are complex, costly, and decentralized; that is, a client organization defines the stages or tasks that constitute the project and then outsources these stages to independent subcontractors. By defining these projects as a series of stages, the client organization can mitigate risk by scheduling numerous review points (or "stage gates") between stages (Santiago & Vakili, 2005). This is the case in many new product development (NPD) projects such as the development of a new drug. Testing most new drugs under development consists of a series of stages (*e.g.*, animal testing, human trials) that are typically outsourced to independent laboratories or hospitals. Given the high cost of these NPD projects[1], researchers and practitioners have focused their attention on various types of contracts (Dayanand and Padman, 2001) that reallocate risks between the client organization (hereafter referred to as the client) and subcontractors in an attempt to increase the likelihood of project success. Empirical evidence generally indicates that these types of incentive contracts can have a significant and positive impact on project outcomes (Meng and Gallagher, 2012).

This paper presents our continuing research on coordinating contracts in decentralized sequential projects; our initial work was described in Chen *et al*. (forthcoming). In this paper, we analyze a specific type of incentive contract that has been used on occasion by various state Departments of Transportation; this contract is commonly known as a "Lane Rental" contract. The name of the contract is based on the fact that subcontractors in transportation projects are required to pay a rental fee for each highway lane they close during their project stage. In this paper, we show that this "Lane Rental" contract coordinates the entire project; that is, it achieves the same maximum profit for the entire project that would be gained in a centralized project.

To analyze this type of contract, we assume that stage durations are described by a non-negative random variable; specifically, we assume that durations follow an exponential distribution with rate r_i that represents the work effort set by the subcontractor. Following previous project management research, we assume that the

[1] Adams and Brantner (2006) estimated the cost of developing a new drug in the U.S. to be in excess of $868M USD.

subcontractors and client incur two types of costs. The first is an overhead/indirect cost per time unit that represents the cost of managing the stages (and project) and increases proportionally with the duration of the stages (and project). The second is a resource cost incurred by subcontractors that increases quadratically with the rate r_i (following Kwon *et al*, 2010). We also assume that the client receives a fixed payment when the project is completed.

The contracts we analyze in this paper are analogous to the previously mentioned "Lane Rental" contract. In the general form of our proposed contract, an initial payment is allocated to each subcontractor but is reduced as the duration of the stage increases (*e.g.*, lane rental fee). This contract is based on two variables, p_i and s_i, that are set by the client where p_i is the initial payment to subcontractor i, and s_i defines a penalty cost per time unit. We note that if $s_i = 0$, the contract is a fixed price contract that is widely used in practice and pays a subcontractor a fixed amount regardless of the stage duration.

To study this contract, we model the negotiation process between the client and independent subcontractors as a Stackelberg game. The client initially sets the values of p_i and s_i at the start of the project; each subcontractor responds by setting their optimal work effort r_i. In this paper, we consider two optimization criteria: (1) maximizing expected profit (when the subcontractor and/or client is risk neutral) and (2) minimizing the probability of incurring a loss (when the subcontractor and/or client is risk adverse). It should be noted that the second criteria is related to the value at risk (VaR) that has been used in analyzing financial portfolios.

We consider two types of incentive contracts. In the first, the payment to the i^{th} subcontractor is equal to $[p_i - s_i t_i]$ where t_i represents the realized duration of the i^{th} stage. In this type of contract, the subcontractor may incur a negative revenue if her stage exceeds some threshold duration (*i.e.*, she would have to pay a penalty to the client). In the second contract, the payment from the client is equal to $max(0, p_i - s_i t_i)$ such that the subcontractor will always receive a non-negative payment from the client (but could still incur a net loss).

We are able to derive numerous results, both analytically and numerically. Initially, we can show that the optimal work rate set by a subcontractor in response to any non-negative values of p_i and s_i set by the client is defined by a closed-form expression that is a function of the client's and subcontractor's overhead cost per time

unit, and the subcontractor's direct resource cost parameter (but not a function of the initial payment p_i). As a result, we are able to derive a closed-form expression for the maximized expected client and subcontractors' profits.

Among other results, we can show that the subcontractor response (in terms of the optimal work rate) is the same whether or not she wants to maximize expected profit (risk neutral) or minimize the probability of incurring a loss (risk adverse). Our work also investigates the relationship between contract types with respect to the client's and subcontractors' expected profit (or probability to avoid a loss). In general, our results indicate that incentive contracts are better for the client but not the subcontractors.

In addition, we are investigating the impact of various contracts (*e.g.*, incentive and fixed price contracts) on the coordination of the entire project and the total project profitability. We show that the "Lane Rental" contract coordinates the overall project and discuss the coordination impacts of other contract forms. We present other implications through both analytical and numerical methods.

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