Research Article

Coordinating a Service Supply Chain under Arms Offset Program's Intervention by Performance-Based Contracting

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This paper investigates a support service supply chain for coordinating with a local third-party logistics provider by arms offset program's intervention and develops a performance-based contracting framework for the coordinating problem, which remains scarce in the literatures. The performance-based contracting framework evaluates payments and profits for the support service by a game-theoretical approach with principal-agent model. We prove that the proposed framework is an effective tool in acquiring the balance between maximum profit and minimum payment for both parties in the coordinating problem without moral hazard issue. A numerical study consolidates the formulated schemes as contracting preference for both parties' decision with a higher profit margin at a lower customer's payment.

1. Introduction

For a complex system (e.g., defense systems, transport vehicles, or oil-platforms), the system support service supply chain is a common and challenging business in global industries today. One of the main drivers in this support service is systems' reliability, since the support service revolves around preventing and responding to unanticipated product malfunctions by the service supply chain. Thus the customers (i.e., the systems' owner such as governments or enterprises) have developed an interest in coordinating an after-sales supply chain in order to sustain systems' availability to optimize the support service cost and to enhance competitive capabilities or synergies in economical/social field. Generally, fulfilling the increasing support service demands enables the service supply chains to generate higher profit margins than systems' sales and to constitute a significant part of the industrial economy [1].

Since the system support services are often provided and consumed by two different organizations (i.e., the customer and the service provider), the issue of contracting between them becomes important. In practice, the service supply chain for system support service is categorized into a resource-based contract (RBC) and a performance-based

contract (PBC). The RBC is a traditional systems' support strategy by amounting resources such as spare parts, labors, and consumable resources in contract duration. By contrast, the PBC contains a service level agreement with respect to a system performance output (e.g., the system availability) at the consumer site and concentrates on performance results rather than on material results as huge-crowd strategy traditionally done. The strategy is often referred to as "performance-based logistics" (PBL) in defense industry or "power by hour" logistics (PBH) in commercial airlines [2].

However, for military system support service, most studies referred more generally to the customer (i.e., purchasing country, G_P) along with the service supply chain by system's original equipment manufacturers (OEM) relation ($G_P - \text{OEM}$) and, namely, lacked attentions on the customer along with a domestic third-party logistics providers (3PL) relation ($G_P - 3\text{PL}$). The $G_P - 3\text{PL}$ support service is usually induced by arms offset program, which is widely implemented in the newly industrial countries such as Taiwan [3]. In national arms sales, the arms offset program becomes an essential condition by offering from the OEM. It is a global interactive business driven through the defense OEM (e.g., Boeing or Lockheed Martin) that transfers extra technical or economic benefits to the customer as an incentive mechanism for selling

FIGURE 1: The correlations among G_S , G_P , OEM, and 3PL.

defense systems or services in governmental procurement [4]. Based on the practices in Taiwan [3], a typical arms offset program starts with the arms sale between the customer and the OEM's nation (e.g., US, G_S). Follow the arms sales deal ($G_S - G_P$); the OEM has to fulfill the offset obligations by rewarding the customer's requirements for enriching the customer's economy synergy [5]. Figure 1 presents the close loop correlations and compares different types of the service supply chain form by the OEM and 3PL.

Additionally, most literatures are generally limited into the advantages of support service relations between $G_S - \text{OEM}$ and $G_P - \text{OEM}$ service supply chain [1, 6–9], which seldom address themselves to $G_P - 3\text{PL}$ service supply chain relation under arms offset program's intervention. Hence, the shortcomings for $G_P - 3\text{PL}$ coordinating problem provide a research opportunity. In this paper, we develop an enhanced PBC model, which was proposed by Kim et al. [1], for $G_P - 3\text{PL}$ coordinating problem. Specifically, we address the following research questions:

- (1) How do they interact in $G_P - 3\text{PL}$ service supply chain relation by intervention from arms offset program?
- (2) How to make a quantifiable assessment to approach the customer's minimum payment for budget planning and 3PL's maximum profit before start bargaining for $G_P - 3\text{PL}$ coordinating problem? Additionally, how does the quantifiable assessment influence decisions for $G_P - 3\text{PL}$ service supply chain relation?

For the coordinating problem for $G_P - 3\text{PL}$ service supply chain, this paper develops a coordinating framework by using the principle-agent model and game-theoretic analysis to assess a rational decision preference for the coordinating problem of $G_P - 3\text{PL}$ service supply chain with multiple PBC schemes in a self-interested manner. The remainder of this paper is organized as follows. Section 2 summarizes the literatures related to the PBC. Section 3 defines the proposed coordinating framework. Section 4 implements a practical coordinating problem for $G_P - 3\text{PL}$ service supply chain in

Taiwan to demonstrate how the framework presents qualitative and quantitative analyses into the problem. Section 5 draws conclusions and gives directions for future research.

2. Literature Overview

Since large numbers of literatures referred to service supply chain optimization, which has been widely measured by performance outcome characteristic such as system availability, thus this section concentrates on the research tendency in the PBC territories in principal-agent based approach and operational availability based approach. Furthermore, considering literatures on the redundancy allocation and conceptual principle-agent framework allows us to discover a new research tendency and develop a quantitative decision framework for assessing $G_P - 3\text{PL}$ coordinating problem.

Our study is closely related to the design and deployment of profitable close-loop service supply chain by using principal-agent based approach, which has examined the principal-agent model for PBC. Scherer [10] introduced the theory of contract incentives for optimal cost premium under risk aversion conditions in defense procurement. McAfee and McMillan [11] introduced an analysis of bidding for government procurement under significant cost-related risks. As the complexity of the products and production processes increased, the contracting strategy of managing production processes from basic raw material resources to sophisticated products became a less viable option [12]. Additionally, Ashgarizadeh and Murthy [13] indicated that maintenance outsourcing by an external agent may be specified for maintenance and cost issues and develop a stochastic model to study the impacts on the agents' expected profits and the optimal strategies by using a game theoretic formulation.

Several models were developed to encompass numerous conflicting objectives from both principal and agents because maintenance contracts were growing more complex. Bowman and Schmee [14] performed a simulation to explore the operational issues and sensitivities associated with these contracts and examined a case of aircraft engine maintenance service in a large corporation to help mitigate and manage uncertainty risks. Kim et al. [1] focused on outcome-based reimbursement policies for risk aversion by using the principal-agent model and studied cost-plus and fixed-price contracts in the context of logistics support to measure the after-sales supply chain. Additionally, Kim et al. [6] also compared efficiencies of two widely used contracts, based on sample-average downtime and cumulative downtime, and identified the supplier's ability to influence the frequency of disruptions as an important factor in determining which contract performs better. Öner et al. [15] introduced a quantitative model to support the decision on the reliability level of a critical component during the design phase to formulate the costs, which were affected by the reliability level of the component and its spare parts inventory throughout a service contract. Finally, Fang and Wong [16] applied a hybrid case-based reasoning approach in the pre- and postnegotiation phases to support adaptive negotiation strategy for buyer-seller negotiations in SCM applications; Yu and Wong [17] presented an agent based negotiation model to automate

the supplier selection process involving a bundle of products with synergy effect; Jin et al. [18] proposed a principal-agent model by attaining multiple objectives such as maximizing the service profitability, lowering the support cost, and ensuring the system availability; and Liu et al. [19] focus on the revenue-sharing contract mechanism design of two stages of service supply chain with consideration of customer customization demand on the background of mass customization service.

In operational availability based approach, it has become a greater concern in recent years because of a large number of literatures on availability optimization for high-tech industrial processes. Kuo and Wan [20] indicated that all these models dealt with either one or both problems for optimizing a system's availability.

(I) *Availability Allocation*. Components or subsystems are appropriately chosen such that the overall system availability is either maximized or meets the design requirement by deciding which option to choose among alternatives (with the same functionality) or to what level to improve the availability of the component.

(II) *Redundancy Allocation*. It is a technique to put extra parts into the system as failure backups. The actual implementation of this approach is often subject to design or resource constraint by deciding how many identical components to use in parallel.

For both allocations, Öner et al. [15] indicated that the system's availability might be increased by providing a higher investment in system's design to conclude an optimization against certain constraints such as budget-balance, performance, acquisition, production, or operation. Additionally, researches for both availability and redundancy allocations usually concentrated on cost issues before system's acquisition phase (e.g., material acquisition, design, and manufacturing); thus they often result in suboptimal solution by ignoring the after-sales services (e.g., logistics and maintenance) costs [2]. Hence, the PBC was widely applied into industrial practices such as modeling supply chain performance and stability [1, 6], green supply chain management [21], making decisions on integrating production and maintenance [22], and coordination for fixed lifetime products with permissible delay in payments [23].

By reviewing the aforementioned literatures, most of them concentrated on an OEM response to its own system's performance output (e.g., availability) through various contracting schemes. As a result, the coordinating problem for G_P -3PL service supply chain remains scarce in the literatures. Hence this paper aims at G_P - 3PL coordinating problem as in the field through support service contract under a service supply chain with given reliability level, which is a necessary complement on principle-agent approach in the PBC.

3. Model Formulation

In this section, we formulate a coordinating framework by using the principle-agent model and game-theoretic

approach to assess a rational decision preference for a G_P - 3PL_{*i*} coordinating problem. In the absence of coordination, both of the parties make decisions to minimize their own costs and maximize their expected utilities such as performance outcome or service profit. Notations used in this paper are listed as follows:

a_i : 3PL_{*i*}'s cost reduction effort.

B_i : 3PL_{*i*}'s backorder.

c_i : 3PL_{*i*}'s fixed cost.

C_i : 3PL_{*i*}'s total cost.

$f_i(x)$: *i*th system's probability density function (PDF).

$F_i(x)$: *i*th system's cumulative distribution function (CDF).

G_P : the country that purchases *i*th system.

G_S : the OEM's country who sells *i*th system.

$|\bar{H}|$: Bordered Hessian determinant.

k_i : a parameter for 3PL_{*i*}'s incurring disutility $\psi(a_i)$.

L_i : 3PL_{*i*}'s repair lead time distribution for the system.

n : distinct systems in a vehicle.

M : numbers of vehicle in a fleet.

O_i : 3PL_{*i*}'s repair pipeline (on-order).

q_i : frequency summation of G_P 's $E[U_p(T_i(C_i, B_i))]$ and 3PL_{*i*}'s $E[U_i(T_i(C_i, B_i))]$.

r_i : 3PL_{*i*}'s risk aversion ratio.

S_i : *i*th system's inventory level, which is set by G_P .

$T_C(C_i, B_i)$: cost-plus outsourcing scheme.

$T_F(C_i, B_i)$: fixed price outsourcing scheme.

$T_P(C_i, B_i)$: fixed price combined with penalty item outsourcing scheme.

$T_B(C_i, B_i)$: performance-based outsourcing scheme.

α_i : cost premium weighting factor in contract.

ε_i : 3PL_{*i*}'s uncertainty in total cost.

δ_i : Lagrange multiplier.

η_{hi} : 3PL_{*i*}'s hardware cost.

η_{ai} : 3PL_{*i*}'s software cost.

η_{mi} : 3PL_{*i*}'s unit cost for maintenance actions.

λ_i : Poisson rate.

μ_i : number of failed system.

v_i : penalty weighting factor in contract.

$\psi_i(a_i)$: 3PL_{*i*}'s incurring disutility.

ω_i : G_P 's budget constrain.

FIGURE 2: The varied coordinating problems between the OEM and 3PL_i supply chain.

3.1. Problem Statements. Consider the coordinating problem under G_p –3PL supply chain for a system support service. The principal is G_p that acquires N identical assembled vehicles (e.g., helicopter or jet fighter). Each vehicle is composed of n distinct major systems (e.g., jet engine or avionics) and each of them can be maintained by a chosen 3PL_{*i*} through the arms offset program to fulfill the G_p 's strategies for cultivating G_p 's local industries. Assume no system is discarded during the vehicle's entire lifecycle because the system is typically expensive and has a long-turn operational lifecycle. Failures occur with a Poisson rate λ_i and independently from failures of other systems; thus $\text{Cov}[\lambda_i, \lambda_j] = 0, \forall i \neq j$.

Notably, G_p maintains an inventory of spared system and employs one-for-one base stock policy. The inventory is very unique but reasonable for the following considerations. First, in most arms sales cases, the G_p usually purchases extra systems in advance to prevent uncertainties, such that G_p fails bargain with the chosen 3PL_{*i*} or the OEM does not release maintenance technologies to 3PL_{*i*} through an arms offset program [24]. Second, such inventory policy allows for an immediate replacement while a failed system enters 3PL_{*i*}'s repair facility or occurs as a backorder B_i to affect system's availability. Figure 2 illustrates the maintenance sequence comparisons between the current G_p –OEM and proposed G_p –3PL_{*i*}.

The backorder B_i in the service supply chain is related with a given inventory level S_i and a stationary random pipeline (on-order) O_i at a random point in time through $E[B_i | S_i] = (O_i - S_i) \geq 0$. Furthermore, Palm's theorem states that O_i is Poisson distributed for any repair lead time distribution, with the mean $\mu_i \equiv \lambda_i L_i$. The failure rate's approximation is close to be fixed because λ_i is the amount of failure units in the maintenance sequence. In practice, consider $E[B_i | S_i] \leq \lambda_i L_i \ll n_i N + S_i$ is satisfied for most repairable systems. This assumption ensures the amount of system maintenance at any given time is relatively small and ignores the correction caused by state dependency.

Proposition 1. *The expected backorder $E[B_i | S_i]$ is decreasing and convex in S_i .*

Proof. Let the repair pipeline $O_i \in [0, \infty)$ be distributed continuously by a cumulative distribution function (CDF) $F_i(O_i) \in [0, 1]$ and a probability density function (PDF) f_i . Thus the distribution of B_i is obtained by determining $\Pr(B_i \leq x | S_i) = \Pr(O_i \leq x + S_i)$.

Furthermore, consider the expected backorder $E[B_i | S_i] = \int_{S_i}^{\infty} (1 - F_i(x)) dx$; therefore the $dE[B_i | S_i]/dS_i = -1 + F_i(S_i) \leq 0$ and $d^2E[B_i | S_i]/dS_i^2 = f_i(S_i) \geq 0$.

Hence we conclude the expected backorder $E[B_i | S_i]$ is decreasing and convex in S_i . $\square$

3.2. Coordinating Contracting Terms and Utilities. For generating 3PL_{*i*}'s total cost C_i for the support service, we firstly consider 3PL_{*i*}'s fixed cost $c_i = \eta_{hi} + \eta_{ai} + \eta_{mi}E[u_i]$, where η_{hi} denotes hardware costs to construct facility, η_{ai} denotes software costs such as intellectual authorities or technical assistance from the OEM, η_{mi} denotes unit cost for maintenance, and $E[u_i]$ represents expected demands in contract duration. In practices, the fixed cost c_i may be reduced by 3PL_{*i*}'s cost reduction effort a_i with an incurring disutility $\psi_i(a_i)$, which is increasing convex (i.e., $\psi_i'(a_i) > 0$ and $\psi_i''(a_i) > 0$) and which can be assessed by G_p . In this convention, the cost reduction effort a_i is 3PL_{*i*}'s own discretionary decision; hence G_p does not subsidize 3PL_{*i*}'s internal cost but only reimburses the undisputed direct costs of maintenance. Chen [25] presented a quadratic functional form to verify the disutility $\psi_i(a_i)$ through $\psi(a_i) = k_i a_i^2 / 2, \forall k_i \in \mathbb{R}^+$. This assumption generates compact expressions without fundamentally changing the insights of the framework.

Secondly, Laffont and Tirole [26] introduced a relationship to generate the basis of the 3PL_{*i*}'s total reimbursement cost $C_i = c_i - a_i + \varepsilon_i$, where ε_i denotes the uncertainty. Let ε_i be uncorrelated with the backorder B_i and another different system, which is supported by a 3PL_{*j*} ($\forall i \neq j$); thus $\text{Cov}[\varepsilon_i, B_i] = \text{Cov}[\varepsilon_i, \varepsilon_j] = \text{Cov}[\varepsilon_i, B_j] = 0$. Notably, this assumption does not consider 3PL_{*i*}'s efforts impact on the availability and repair capabilities of the system, with or without extra technical assistance from the system's OEM.

Thirdly, Kim et al. [1] integrated contract payment terms by comprising a fixed payment ω_i , a reimbursement cost C_i , and a backorder-contingent incentive payment B_i to construct the PBC form through

$$T_i(C_i, B_i) = \omega_i + \alpha_i C_i - v_i B_i \eta_m, \quad (1)$$

where $\alpha_i \in (0, 1)$ denotes the G_p 's cost-premium weighting factor for 3PL_{*i*} and $v_i \in (0, 1)$ denotes the penalty weighting rate for unacceptable outcomes such as $E[B_i | S_i]$.

Additionally, considering that 3PL_{*i*} is risk aversion, Chen [25] presented that 3PL_{*i*}'s net income is normally distributed and the expected mean-variance utility can be estimated as

$$E[U(x)] = \vartheta_x - \frac{r}{2} \sigma_x^2, \quad (2)$$

where x denotes the normal distributed net income, ϑ_x represents the mean of x , and σ_x^2 presents the variance. Furthermore, $r \geq 0$ denotes a constant risk aversion factor, such that the greater the r is, the more the risk aversion

3PL_i has. This utility function has been widely used in recent operations-management research because of its tractability and allows us to derive the expected profit function for 3PL_i by various contract scheme $T(C_i, B_i)$ through

$$\begin{aligned} E[U_i(T(C_i, B_i) - C_i) - \psi_i(a_i) | a_i, S_i] \\ = \omega_i - (1 - \alpha_i)(C_i - a_i) - v_i E[B_i | S_i] - \frac{k_i a_i^2}{2} \\ - \frac{(r_i(1 - \alpha_i)^2 \text{Var}[\varepsilon_i] - r_i v_i^2 \text{Var}[B_i | S_i])}{2}, \end{aligned} \quad (3)$$

where $\omega_i - (1 - \alpha_i)(C_i - a_i) - v_i E[B_i | S_i]$ term represents the expected income, $-k_i a_i^2/2$ term represents the internal disutility for exerting cost reduction efforts, and $-(r_i(1 - \alpha_i)^2 \text{Var}[\varepsilon_i] - r_i v_i^2 \text{Var}[B_i | S_i])/2$ term represents risk premiums associated with cost and performance uncertainties with $\text{Var}[B_i | S_i]$.

Similarly, the expected payment (i.e., budget constraint) utility function $E[U_p(T_i(C_i, B_i)) | a_i, S_i]$ for the support service can be derived through

$$\begin{aligned} E[U_p(T_i(C_i, B_i)) | a_i, S_i] \\ = \omega_i - \alpha_i(C_i - a_i) - v_i E[B_i | S_i] + \frac{r_i \alpha_i^2 \text{Var}[\varepsilon_i]}{2} \\ + \frac{r_i v_i^2 \text{Var}[B_i | S_i]}{2}, \end{aligned} \quad (4)$$

where $\omega_i - \alpha_i(C_i - a_i) - v_i E[B_i | S_i]$ represents expected net payment.

3.3. Game-Theoretic Analysis to Generate Dominate Strategy. This subsection considers $G_p - 3PL$ coordinating problem is enforced by Nash bargaining in using cooperative game theory because both parties constitute a coalition by selecting contracting schemes and enforcement [27]. Thus the objectives for $G_p - 3PL$ coordinating problem can be summarized as

- (I) Determine appropriate incentives through an AOP to a chosen domestic 3PL_i for enriching G_p 's economic utilities.
- (II) Access G_p 's preference decision by determining a minimal payment and 3PL_i's maximal profit for the support service.

Additionally, the total cost C_i and backorder level B_i are functions of the cost reduction effort a_i and the i th system's inventory S_i . This allows 3PL_i to partially control the performance by setting a_i to maximize G_p 's expected profit and risk-averse. Hence, 3PL_i's actions can be observable by G_p to access the effectiveness with widely used contracting schemes by controlling v_i and α_i through (3) and (4).

Scheme 2. A pure fixed price contract $T_F(C_i, B_i)$ by $v_i = 0$ and $\alpha_i = 0$; thus, the contracting term is $T_F(C_i, B_i) = \omega_i$.

TABLE 1: Normal-form game for various coordinating schemes.

3PL _i		
	$\alpha_i = 0$	$0 < \alpha_i < 1$
G_p		
$v_i = 0$	$T_F(C_i, B_i) = \omega_i$	$T_C(C_i, B_i) = \omega_i + \alpha_i C_i$
$0 < v_i < 1$	$T_P(C_i, B_i) = \omega_i - v_i B_i$	$T_B(C_i, B_i) = \omega_i + \alpha_i C_i - v_i B_i$

Scheme 3. A fixed price contract with penalty items $T_P(C_i, B_i)$ by $0 < v_i < 1$ and $\alpha_i = 0$ results in $T_P(C_i, B_i) = \omega_i - v_i B_i$.

Scheme 4. A cost-plus contract $T_C(C_i, B_i)$ with full reimbursement by $v_i = 0$ and $0 < \alpha_i < 1$ results in $T_C(C_i, B_i) = \omega_i + \alpha_i C_i$.

Scheme 5. A performance-based contract $T_B(C_i, B_i)$ by $0 < v_i < 1$ and $0 < \alpha_i < 1$ results in $T_B(C_i, B_i) = \omega_i + \alpha_i C_i - v_i B_i$.

Table 1 shows all four schemes (i.e., feasible strategies) for $G_p - 3PL_i$'s coordinating problem within a two-player normal-form game for theoretic analysis.

In practices, Table 1 is sufficient to represent a portfolio for both parties' perspectives. First, G_p desires to access a minimal budget-balancing and risks for system availability by regarding penalties v_i to ensure G_p 's claim. Second, the 3PL_i desires to access 3PL maximal profits by determining a cost-sharing effort α_i . Table 2 represents the expected utility for four contracting schemes by substituting (3) and (4).

In a $G_S - G_p$ arms sales case, G_p sets inventory S_i , selects contract terms $(\omega_i, \alpha_i, v_i)$ and proceeds to anticipate 3PL_i's effort a_i to achieve a minimal total disutility, which subjects to the i th system's availability requirement (i.e., the backorder constraint B_i). Therefore 3PL_i chooses a_i to maximize 3PL expected profit utility by giving contracting schemes and parameters $(\omega_i, \alpha_i, v_i, S_i)$. Hence 3PL_i solves 3PL maximal expected utility problem by evaluating schemes which subject to $\max_{a_i} \text{Arg}_{T(C_i, B_i)} E[U_i(T(C_i, B_i) - C_i) - \psi_i(a_i) | a_i, S_i] > 0$ within the individual rationality constraint (IR_t) to ensure the 3PL_i's participation. This becomes a typical moral hazard problem to allow each IR_t to bind at the optimal solution [1, 24]. Similarly, G_p can exact all surplus from 3PL_i by setting an appropriate fixed payment (ω_i) to solve G_p 's problem as $\min_{\omega_i, \alpha_i, v_i, S_i} \text{Arg}_{T(C_i, B_i)} E[U_p(T_i(C_i, B_i)) | a_i, S_i]$.

Additionally, 3PL_i's cost reduction effort a_i is observable in real arms offset program practices (i.e., the first-best solution in principle-agent model). Let δ_i be the Lagrange-multiplier which associates with the system availability constraint to convert the expected utility with Lagrangian $L_i = E[U_i - \psi_i] - \delta_i E[U_p]$ with (3) and (4) to determine partial derivatives of $\partial L_i / \partial a_i$, $\partial L_i / \partial r_i$, and $\partial L_i / \partial \delta_i$ as

$$\begin{aligned} a_i &= \frac{1}{k_i}, \\ r_i &= \frac{2(C_i - \omega_i + \alpha_i(C_i - 1/k_i) + v_i E[B_i | S_i])}{(\alpha_i^2 \text{Var}[\varepsilon_i] + v_i^2 \text{Var}[B_i | S_i])}, \end{aligned}$$

TABLE 2: Expected utility of various outsourcing schemes.

Scheme	G_P	$3PL_i$
$T_F(C_i, B_i)$	ω_i	$\omega_i - (C_i - a_i)$
$T_P(C_i, B_i)$	$\omega_i - v_i E[B_i S_i] + r_i v_i^2 \frac{\text{Var}[B_i S_i]}{2}$	$\omega_i - (C_i - a_i) - v_i E[B_i S_i] - \frac{k_i a_i^2}{2} - r_i \frac{\text{Var}[\varepsilon_i]}{2} - r_i v_i^2 \frac{\text{Var}[B_i S_i]}{2}$
$T_C(C_i, B_i)$	$\omega_i - \alpha_i (C_i - a_i) + r_i \alpha_i^2 \frac{\text{Var}[\varepsilon_i]}{2}$	$\omega_i - (1 - \alpha_i)(C_i - a_i) - \frac{k_i a_i^2}{2} - r_i (1 - \alpha_i)^2 \frac{\text{Var}[\varepsilon_i]}{2}$
$T_B(C_i, B_i)$	$\omega_i - \alpha_i (C_i - a_i) - v_i E[B_i S_i] + r_i \alpha_i^2 \frac{\text{Var}[\varepsilon_i]}{2} + r_i v_i^2 \frac{\text{Var}[B_i S_i]}{2}$	$\omega_i - (1 - \alpha_i)(C_i - a_i) - v_i E[B_i S_i] - \frac{k_i a_i^2}{2} - r_i (1 - \alpha_i)^2 \frac{\text{Var}[\varepsilon_i]}{2} - r_i v_i^2 \frac{\text{Var}[B_i S_i]}{2}$

$$\delta_i = \frac{((1 - \alpha_i)^2 \text{Var}[\varepsilon_i] - v_i^2 \text{Var}[B_i | S_i])}{(\alpha_i^2 \text{Var}[\varepsilon_i] + v_i^2 \text{Var}[B_i | S_i])}. \quad (5)$$

Proposition 6. In $T_P(C_i, B_i)$, $T_C(C_i, B_i)$, and $T_B(C_i, B_i)$, $\text{Arg}_{T(C_i, B_i)} E[U_i - \psi_i]$ is decreasing and convex in α_i and v_i .

Proof. For $3PL_i$'s expected utilities are subjected to G_P 's constrained budget; the second-order necessary-and-sufficient conditions encompass the algebraic sign of the second-order partial differential $\partial^2 L$ at a stationary point by the Bordered Hessian determinant $\text{Arg}_{T(C_i, B_i)} |\overline{H}_i|$ [28] to determine the second-order necessary-and-sufficient condition:

$$\begin{aligned} \text{Arg}_{T(C_i, B_i)} |\overline{H}_i| &= \begin{vmatrix} 0 & \frac{\partial L}{\partial \alpha_i} & \frac{\partial L}{\partial r_i} \\ \frac{\partial L}{\partial \alpha_i} & \frac{\partial^2 L}{\partial \alpha_i^2} & \frac{\partial^2 L}{\partial \alpha_i \partial r_i} \\ \frac{\partial L}{\partial r_i} & \frac{\partial^2 L}{\partial r_i \partial \alpha_i} & \frac{\partial^2 L}{\partial r_i^2} \end{vmatrix} \\ &= \frac{k_i (\alpha_i^2 \text{Var}[\varepsilon_i] + v_i^2 \text{Var}[B_i | S_i])}{4} \end{aligned} \quad (6)$$

given $\forall k_i > 0$, $\text{Var}[\varepsilon_i] > 0$, and $\text{Var}[B_i | S_i] > 0$ to determine various schemes $|\overline{H}_i|$. In Scheme 2 (i.e., $T_F(C_i, B_i)$ with $v_i = \alpha_i = 0$), $\text{Arg}_{T_F} |\overline{H}_i| = 0$ concludes that the second-order sufficient condition is not satisfied for maximum $\text{Arg}_{T(C_i, B_i)} E[U_i - \psi_i]$. In $T_P(C_i, B_i)$, $T_C(C_i, B_i)$, and $T_B(C_i, B_i)$ schemes, $\text{Arg}_{T(C_i, B_i)} |\overline{H}_i| > 0$ by giving $v_i > 0$ or $\alpha_i > 0$.

Hence we conclude in $T_P(C_i, B_i)$, $T_C(C_i, B_i)$, and $T_B(C_i, B_i)$ that $\text{Arg}_{T(C_i, B_i)} E[U_i - \psi_i]$ is decreasing and convex in α_i and v_i . $\square$

Proposition 6 proves $T_F(C_i, B_i)$ is not a satisfied maximum expected utilities because the $T_F(C_i, B_i)$ totally ignores $3PL_i$'s effort a_i and $\text{Var}[B_i | S_i]$, but this result can be a benchmark against other contracting alternatives.

TABLE 3: Basic considerations about case's parameters.

G_P	$3PL_i$
Contract duration 8 years	Expected hardware cost $E[\eta_h]$: \$2.5M
Budget constraint $\omega_i = \$20.0M$	Expected software cost $E[\eta_a]$: \$1.5M
Type T engine $n_i = 300, S_i = 15$	Breakeven: 5 years
Unit cost $D_i = \$0.5M$	Unit maintenance cost η_m : \$0.2M
Max. penalty rate $v_i = 10\%$	Profit: 10% of η_m
	$E[B_i] = 11$
	$E[u_i] = 14/\text{year}$

4. Numerical Analysis

In this section, the subsequent quantitative analysis presents how G_P starts to coordinate a $G_P - 3PL_i$ service supply chain with a chosen $3PL_i$, who accepts the technology transfer from i th system's OEM through an arms offset program in Taiwan. This typical practice demonstrates how the proposed framework can be applied into an eight-year after-sales support service. Notably, the proposed framework reasonably specifies budget-balance constraints, regulations, costs, cost premium, and penalty parameters.

Total $N = 150$ military twin-engine helicopters are deployed in Army, Navy, and Air Force. The helicopters are powered by type T turboshaft engine, plus 5% for inventory by G_P . Table 3 represents considerations under a general operation (i.e., without critical mission requirements), cost constrain, and maintenance capability.

Based on giving a selected level for availability and incentives to support $3PL_i$'s software cost η_a (i.e., the OEM's technical assistance) by arms offset program. $3PL_i$ starts to establish the maintenance capacity for the type T engine system. In this practice, we first derive the expected budget constrain, which meets the large procurement definition's threshold in the "Enforcement Rules of Government Procurement" in G_P . Thus, the maximum penalty rate $\text{Max } v_i \approx 0.1$. Next, in real practice, the maximum cost reduction $\text{Max } a_i \approx 0.1E[c_i]$ (i.e., $k_i = 1/a_i \approx 0.46$), and the cost premium weighting factor $\text{max } \alpha_i = \eta_i/C_i \approx 0.08$. Additionally,

TABLE 4: The numerical results of each scheme with $r_i = 26$.

Var $[B_i S_i]$	$r_i = 26$ Var $[\varepsilon_i]$	G_p 's payment (million dollars)				3PL $_i$'s profit (million dollars)			
		T_F	T_P	T_C	T_B	T_F	T_P	T_C	T_B
1	0.01	20.00	19.81	18.59	18.39	2.31	0.84	2.52	2.28
1	0.05	20.00	19.81	18.59	18.40	2.27	0.32	2.08	1.84
1	0.10	20.00	19.81	18.59	18.40	2.22	-0.33	1.53	1.29
1	0.15	20.00	19.81	18.60	18.40	2.17	-0.98	0.98	0.74
1	0.20	20.00	19.81	18.60	18.41	2.12	-1.63	0.43	0.19
2	0.01	20.00	19.83	18.59	18.42	2.31	0.81	2.52	2.25
2	0.05	20.00	19.83	18.59	18.42	2.27	0.29	2.08	1.81
2	0.10	20.00	19.83	18.59	18.43	2.22	-0.36	1.53	1.26
2	0.15	20.00	19.83	18.60	18.43	2.17	-1.01	0.98	0.71
2	0.20	20.00	19.83	18.60	18.43	2.12	-1.66	0.43	0.16

TABLE 5: Descriptive statistics for G_p 's expected budget payments.

(\$USM)	T_F	T_P	T_C	T_B
Mean	20.000	19.818	18.594	18.412
Standard deviation	0.000	0.027	0.007	0.032
Mode	20.000	19.780	18.592	18.366
Median	20.000	19.814	18.618	18.408
Variance	0.000	0.001	0.000	0.001
$E[U_p(T_i(C_i, B_i)) a_i, S_i]$	20.000	19.818	18.594	18.412

the risk aversion $0 \leq r_i \leq 51$, $\forall r_i \in R^+$, can be determined by giving $\text{Max Var}[B_i] \approx 0.2E[B_i]$ and $\text{Max Var}[\varepsilon_i] \approx 0.2C_i$. Hence, the required numerical solutions for all four schemes can be determined in Table 4 by giving $r_i = 26$.

4.1. G_p 's Expected Payment and Preference. This subsection considers uncertainties of four various contract schemes by setting the coefficients that are positively correlated (i.e., $\text{Var}[\varepsilon_i] \propto \text{Var}[B_i | S_i]$) to determine G_p 's payment and rational preference. Notably, consider that $E[U_p(T_i(C_i, B_i)) | a_i, S_i]$ is a stationary stochastic process by giving $r_i \in (0, 51) \in \mathbb{Z}$, $\text{Var}[B_i | S_i] \in (1, 2) \in \mathbb{Z}$, and $\text{Var}[\varepsilon_i] \in (0.01, 0.2)$ with interval 0.01 which allows to calculate the frequency of uniform discrete random variable for every possible payment (2,080 solutions for each scheme) because there are same probabilities:

$$E[U_p(T_i(C_i, B_i)) | a_i, S_i] = \frac{\sum_{r_i} \sum_{B_i} \sum_{\text{Var}(\varepsilon_i)} T_i(C_i, B_i)}{q_i}, \quad (7)$$

where q_i denotes the frequency summation in $E[U_p(T_i(C_i, B_i)) | a_i, S_i]$ (i.e., $q_i = 2,080$). Hence, G_p 's histogram and the descriptive statistics for payments can be derived as Figure 3 and Table 5.

FIGURE 3: Frequency for numerical solutions of G_p 's expected payments.

Furthermore, the payments of four schemes can be resulted by ordered as

$$\begin{aligned} E[U_p(T_F(C_i, B_i))] &> E[U_p(T_P(C_i, B_i))] \\ &> E[U_p(T_C(C_i, B_i))] \\ &> E[U_p(T_B(C_i, B_i))]. \end{aligned} \quad (8)$$

FIGURE 4: Frequency for numerical solutions of 3PL_i's expected profits.

Thus G_P 's rational preference can result as

$$T_B(C_i, B_i) > T_C(C_i, B_i) > T_P(C_i, B_i) > T_F(C_i, B_i). \quad (9)$$

Based on the order steps of play by Nagarajan and Sošić [27] and the numerical results, G_P will rationally offer the robust $T_B(C_i, B_i)$ scheme to 3PL_i as G_P 's first offer for $G_P - 3PL_i$ coordinating problem. Notably, various uncertainties (i.e., $\text{Var}[B_i | S_i]$, $\text{Var}[\varepsilon_i]$ and r_i) do not affect the G_P 's expected payments because numerical solutions indicate the expected payments are maintained as certain constant in each scheme. Hence, we conclude the proposed decision framework success provides a robust scheme ($T_B(C_i, B_i)$) as dominating strategy for $G_P - 3PL_i$ coordinating problem within a budget constraint.

4.2. 3PL_i's Expected Profit. 3PL_i's expected profit function $E[U_i(T(C_i, B_i) - C_i) - \psi_i(a_i) | a_i, S_i]$ is also a stationary stochastic process by giving r_i , $\text{Var}[B_i | S_i]$, and $\text{Var}[\varepsilon_i]$. Thus the frequency of uniform discrete random variable can be calculated for every possible profit (i.e., 2,080 solutions in

TABLE 6: Descriptive statistics for 3PL_i's expected profits.

(\$USM)	T_F	T_P	T_C	T_B
Mean	2.215	-0.382	1.496	1.238
Standard deviation	0.058	1.177	0.983	0.998
Mode	2.310	0.995	2.629	2.409
Median	2.215	-0.057	1.783	1.514
Variance	0.003	1.385	0.966	0.997
$E[U_i(T_i(C_i, B_i))]$	2.215	-0.382	1.496	1.238

each scheme) to determine the $E[U_i(T(C_i, B_i) - C_i) - \psi_i(a_i) | a_i, S_i]$ by (3). 3PL_i's histogram and the descriptive statistics can be derived as Figure 4 and Table 6.

Furthermore, the profits of four schemes can result in order as

$$\begin{aligned}
 E[U_i(T_F(C_i, B_i))] &> E[U_i(T_C(C_i, B_i))] \\
 &> E[U_i(T_B(C_i, B_i))] \\
 &> [U_i(T_P(C_i, B_i))].
 \end{aligned} \quad (10)$$

Based on $\text{Max Arg } E[U_i(T(C_i, B_i) - C_i) - \psi_i(a_i) \mid a_i, S_i] \geq 0$, $3PL_i$ will rationally decline $T_P(C_i, B_i)$ contracting because only $E[U_i(T_P(C_i, B_i))] < 0$. Hence, $3PL_i$'s rational preference can result as

$$\begin{aligned} E[U_i(T_F(C_i, B_i))] &> E[U_i(T_C(C_i, B_i))] \\ &> E[U_i(T_B(C_i, B_i))]. \end{aligned} \quad (11)$$

5. Conclusions

In this paper, we propose a quantitative decision making framework to develop a predictable assessment for solving the unexplored coordinating problem for $G_P - 3PL$ service supply chain by the intervention of arms offset program. The proposed framework firstly formulates the objective functions for $G_P - 3PL$ service supply chain to approximate equilibrium solutions by principle-agent model and secondly assesses the coordinating preference by normal-form game analysis with four schemes. Drawing from the proposed decision framework and analytical results by implementing a typical coordinating practice of $G_P - 3PL$ service supply chain in Taiwan, the following conclusions help us to address the three research questions.

Firstly, regard the interaction of $G_P - 3PL$ service supply chain under arms offset program intervention. During the process, $G_P - 3PL$ interacts on system availability and G_P 's budget constraint toward a take-it-or-leave-it contract to achieve equilibrium solutions for G_P 's minimal payment (i.e., budget constraint) and $3PL_i$'s positive profit.

Secondly, how does the assessment consider the contracting decisions? G_P concerns how to determine a minimal payment to enrich the economic utilities, i th system's availability, and $3PL_i$ concerns how to approach a maximal profit under G_P 's preference contracting schemes. Furthermore, by implementing the coordinating practical $G_P - 3PL$ practice in Taiwan, this paper demonstrates that the proposed decision framework is sufficient to formulate the coordinating problem for $G_P - 3PL$ service supply chain to approximate expected solutions for all various contracting schemes. Notably, the proposed framework does not only provide G_P 's expected budget-balance and rational preference for outsourcing decision, but also determines $3PL_i$'s expected profit.

Thirdly, how does the quantifiable assessment approach bargaining equilibrium under various schemes? Additionally, how does the quantifiable assessment influence decisions for $G_P - 3PL$ service supply chain relation? The proposed framework assesses G_P 's rational preference for outsourcing decision by determining approximated solutions for all outsourcing schemes. Notably, the numerical analysis indicates uncertainties such as $\text{Var}[B_i \mid S_i]$, $\text{Var}[\varepsilon_i]$ and r_i do not affect G_P 's expected payment because which are maintained as certain constant in each schemes. Hence the proposed framework can approach a predictable assessment for the coordinating problem for $G_P - 3PL$ service supply chain.

This paper's innovation firstly investigates the unexplored coordinating problem for $G_P - 3PL$ service supply chain, which is induced by an arms offset program, and secondly

presents a decision framework to assess the problem by considering the uncertainties arising from both support costs and system's availability. Specifically, this paper discovers incentive terms in contracting that exhibit complementarities, such that $3PL$'s cost reduction is induced by an arms offset program. Nevertheless, the limitation in this paper is that the proposed framework only provides a contracting strategy but ignores $3PL$'s efforts for improving system's availability because quantitative research on joint efforts between $G_P - 3PL$ service supply chain and the OEM is still within the early stage.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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