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A decision-making framework to integrate maintenance contract conditions with critical spares management

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ABSTRACT

Maintenance outsourcing is a strategic driver for asset intensive industries pursuing to enhance supply chain performance. Spare parts management plays a relevant role in this premise since its significant impact on equipment availability, and hence on business success. Designing critical spares policies might therefore seriously affect maintenance contracts profitability, yet service receivers and external providers traditionally attempt to benefit separately. To coordinate both chain parties, we investigated whether the spare components pool should be managed in-house or contracted out. This paper provides a decision-making framework to efficiently integrate contractual conditions with critical spares stockholding. Using an imperfect maintenance strategy over a finite horizon, the scheme maximizes chain returns whilst evaluating the impact of an additional part to stock. As result, an original joint value – preventive interval and stock level – sets the optimal agreement to profitably allocate the components pool within the service contract. Subsidization bonuses on preventive interventions and pooling costs are also estimated to induce the service provider to adjust its policy when needed. The proposed contractual conditions motivate stakeholders to continuously improve maintenance performance and supply practices, thus obtaining higher joint benefits.

1. Introduction

Maintenance outsourcing is a strategic means to improve business performance. Outsourcing creates value through the use of external resources by and for companies to acquire and sustain competitiveness [1]. The maintenance function is a main driver of outsourcing since it has excellent potential to achieve cost benefits and enhance performance among partners [2]. This business purpose is meaningful for asset intensive industries – such as mining, aeronautic, or defence – which face substantial investment in maintaining complex equipment and high demand on system availability. For these firms, the main reasons to contract out maintenance tasks rather than perform them in-house are focusing on core business, accessing highly specialized services at competitive costs, and sharing risks [2–5]. When dealing with outsourcing, effective supply chain coordination allows achieving a rewarding situation for all stakeholders [3]. Accordingly, a model capable of coordinately optimizing performance can lead to successful maintenance contracting strategies in capital intensive environments.

Spare parts management has a critical role toward operational efficiency of asset intensive industries. Equipment criticality is defined by the most relevant assets that efficiently and safely sustain production [6]. The operation of such equipment is consequently supported by critical spare parts [7]. Major spare components are related to considerable investment, high reliability requirements, extended lead times, and plant shutdowns with important effects on operational continuity [8]. A method to prevent production loss events is having inventories at hand, especially when either target service levels or backorder penalties are large [9]. This is the case of capital intensive firms, wherein critical spares storage is directly linked to business success due to the impact of stock-outs on assets utilization [7]. As an example, the aviation supply chain holds a remarkable US$ 50 billion in spares inventories to provide availability service [10]. Efficient critical spares stockholding is therefore essential for companies in which success strongly depends on equipment performance.

Maintenance contracts profitability can be significantly affected by critical spares policies. Particularly, the stock of critical repairable spares can be interpreted as a pool of components from where replacements are satisfied [7]. Consistently with the serious impact on operational and financial performance, managing the pool of critical spare components becomes a key to improve profits within the service contract. Nevertheless, as it depends

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on the decision-maker's position, both supply chain parties – service receiver (client) and external provider (agent) – traditionally intend to maximize benefits separately. If the client controls the spare parts pool, there are scarce incentives for the provider to avoid an indiscriminate use of components aside from regular restraints. Conversely, if the agent administers the pool, rational use of components turns reasonable. Critical spares stockholding is a supply chain lever to keep maintenance outsourcing viable for the parties involved.

In order to coordinate the contracting parties, we investigated whether or not the client should outsource the management of the pool of spare components to the agent. This paper provides a decision-making framework to profitably integrate the contractual maintenance strategy with critical spares stockholding. The scheme is based on a joint value – preventive interval and stock level – that maximizes the supply chain returns whilst evaluating the impact of an additional part to stock. Using an imperfect maintenance strategy over a finite horizon, the model leads to an optimal decision to allocate the critical spare components pool within the outsourcing contract. An interesting link is thus created between maintenance performance indicators and supply chain practices.

Having introduced the importance of allocating critical spare parts management within maintenance service contracts for asset intensive industries, the rest of the paper is organized as follows. Section 2 states the differences between the enriched concept of the present paper and relevant existent researches. Section 3 describes the model formulation to integrate maintenance and spares supply indicators. Section 4 presents a case study in the mining industry, which holds substantial spares inventories to ensure system performance. Finally, Section 5 provides the main implications of applying the joint model to coordinate the outsourcing strategy under an asset management perspective.

2. Literature review

The following literature review is structured as the importance of the management of the pool of critical spares within maintenance outsourcing contracts.

As an interesting strategy to achieve cost-benefits, consolidating inventory locations by cooperative pooling has been addressed in [10–13], among other studies. In the context of repairable spares pooling, the cost allocation problem is analyzed using game theoretic models in [14]. Recent implementations are a virtual pooled inventory by managing information systems [15] and a calculation model of spare parts demand, storage and purchase planning in the coal mining industry [16]. When dealing with cooperation in contractual alliances, the study of [17] states the relevance of interfirm trust to deter opportunistic behaviour in a shared ownership structure. Such trust is an important issue related to pooling strategies. A widely applied modeling for repairable items stockholding focused on system availability and spares investment is provided in [18]. Since its accuracy to determine the optimal inventory levels for both single-site and multi-echelon techniques, the above-mentioned model is used to adapt the concept of spare service level in the present paper.

Maintenance outsourcing under supply chain coordination is discussed in [3], a study that deals with incentive contracts terms to coordinate agents and clients by a maintenance policy seeking to optimize the total profit. The work of [4] extends this approach by incorporating realistic conditions, such as imperfect maintenance and finite time-span contract. That model adapts the failure rate by using the system improvement model of [19]. Such concepts of profitable coordination and imperfect maintenance are also used in the present paper to improve the practical applicability for asset intensive operations.

There are studies that specifically deal with allocation spare parts in service contracts. A paper intending to incorporate repair contract selection and spares provisioning under a multicriteria approach is presented in [20]. In [21], a profit-centric model is presented for spares provisioning under a logistics contract for multi-item and multi-echelon scenario. In [22], an inventory model is developed for a repairable parts system by varying failure and repair rates. A dynamic stocking policy to replenish the inventory to meet the time-varying spare parts demand is proposed in [23]. A reliability-based maintenance strategy required for the spares inventory is described in [24], although its scope does not cover contract conditions. Since the relevant effect of warranties as service contracting, a three-partite stochastic model including manufacturer, agent, and customer is presented in [25]. However, none of these works has faced the pool management problem by using the realistic assumptions of imperfect maintenance, finite contract duration, or profitable channel coordination.

Regardless of the extensive literature, the present paper introduces new contributions in terms of formulation and analytical properties. To the best of our knowledge, a model capable of delivering profitable decisions to allocate the pool of critical spare parts within maintenance outsourcing contracts – via the inclusion of imperfect maintenance and the optimal conditions for supply chain coordination – has not been addressed in the literature.

3. Model formulation

Consider a system belongs to a fleet of equipment whose operation is supported by a pool of repairable components. The proposed model optimizes the management decisions of critical spare components within the outsourcing service contract. The formulation is presented in three sections as follows: (i) preventive maintenance (PM) policy under the contractual conditions scheme, (ii) service level associated with the stock of critical spare parts, and (iii) decision-making model to integrate PM interval with optimal spares inventory to maximize global profits. The terms “client” and “agent” will henceforth be adopted to indicate service receiver and external provider, respectively.

3.1. Contractual preventive maintenance policy

Let the maintenance of the fleet system be contracted out by the client to the agent. For sake of self-containment, relevant maintenance contract conditions – such as imperfect maintenance and finite contract horizon – developed in [3,4,19] are described in detail. The scheme is set by the following conditions.

- The interval between preventive interventions (PM interval) is T.
- The agent is free to select the age T at which PM will be performed.
- Direct costs and length of PM are, respectively, C_p and T_p.
- Direct costs and length of corrective interventions are, respectively, C_r and T_r.
- The basic service fee to the agent is p.
- The net revenue of the client after production costs is r.
- The agent sets a minimum expected profit π to participate in the game.
- The finite horizon is as the contract lasts from the beginning of a system life cycle to the end of the n-th overhaul.

The system has a Weibull distribution with shape parameter

$$\beta > 1. \tag{1}$$