

INCENTIVE MAINTENANCE CONTRACTS FOR OPTIMIZING CHANNEL PROFIT

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ABSTRACT

We discuss channel coordination in maintenance outsourcing contracts. We consider a service chain, including a manufacturer and a maintenance contractor that performs the manufacturer's maintenance functions. The manufacturer wishes to maximize uptime whereas the contractor aims to minimize cost. Realizing the two parties have different goals, we propose three coordination methods for inducing the contractor to select the maintenance policy that optimizes the profit of the service chain.

Keywords: Maintenance, Channel Coordination

INTRODUCTION

Effective channel coordination is essential for a business organization to succeed in today's business environment. In the last two decades, the channel coordination issues in supply chains have attracted enormous interest among practitioners and researchers, and a large volume of theoretical and empirical studies has accumulated.

Jeuland and Shugan [1] demonstrate the concept of channel coordination by a simple manufacturer-retailer supply chain in their seminal paper. The basic assumption is that the manufacturer and the retailer have separate profit and cost considerations that lead to different inventory policies. Typically, the retailer's order quantity is smaller than the manufacturer's production lot size. In order to coordinate the channel, the manufacturer offers the retailer an incentive contract in terms of quantity discounts to induce the retailer to increase her order quantity. Channel coordination is achieved if the retailer's order quantity that optimizes her profit under the incentive contract also optimizes the total profit of the supply chain.

The focus of the literature on channel coordination has been primarily on the pricing, and information and material flows in supply systems. In particular, issues associated with supplier contracts have been discussed extensively, because contracts are used to implement channel coordination policies by spelling out explicitly the buyer's and supplier's tasks and duties in normal and other conceivable situations. Detailed literature reviews have been given by Tsay, Nahmias, and Agrawal [27] and Anupindi and Bassok [1].

In this paper, we discuss the channel coordination in the maintenance contract area. It has been well known that a sound maintenance policy is essential to the performance of a manufacturing process [14] [19]. In several recent studies, researchers have established empirical evidence in relating maintenance and the performance of a manufacturing organization, and it has been postulated that total preventive maintenance (TPM), along with just in time (JIT) and total quality management (TQM) are three key practices for achieving lean manufacturing [20] [24].

Design of maintenance policies is a well established research area. In a recent review paper by Wang [29], maintenance is categorized into two main types: preventive and corrective. For a process deteriorating over time or its usage, preventive maintenance (PM) is performed periodically to improve the reliability of the process when the process is functional. Corrective maintenance (CM) is used to restore the process back to operation when it breaks down. It is evident that the purpose of preventive maintenance is to reduce the time required by corrective maintenance and the economic consequence incurred by process failure, and a preventive maintenance schedule should be determined by considering the process failure mechanism, and the cost and time required for the maintenance activities.

In the last decade, many corporations have been outsourcing their non-core business functions to outside contractors in order to improve operation efficiency. The practice is motivated by several potential benefits including: (1) The corporation can focus on its core business, (2) Contractors can provide high quality service with lower cost because maintenance is contractors' core business [17]. In a recent survey by *IndustryWeek*, plant managers rated plant maintenance the second most effective business function to outsource, second only to transportation [23]. Maintenance outsourcing has been commonly seen in office equipments, medical (hospital) equipments, airplane engines and brakes, computer hardware and networks, and manufacturing processes. Furthermore, a maintenance outsourcing contract typically involves a significant financial arrangement and a long term relationship between a maintenance contractor and its customers. For example, GE Engine Services recently signed with Skywest Airlines a 16-year maintenance contract valued at \$1 billion to perform engine maintenance on the carrier's fleet of Canadair Regional Jets [5]. In addition, it was estimated that outsourced equipment maintenance represents a \$26 billion industry in healthcare [26]. Consequently, the design of maintenance contracts to ensure channel coordination and a win-win situation for all parties involved are practical and important issues.

Although quite a few maintenance models have been proposed [21] [29], most of the studies are based on the assumption that maintenance is an independent function of a manufacturing process. Recently, researchers have developed models for finding the optimal maintenance policy when it is integrated with other functions. For example, Srinivasan and Lee [22] propose a model for finding the optimal maintenance policy when the production and maintenance

functions are integrated. Yeh and Lo [30] consider a joint decision for preventive maintenance and warranty for repairable products. To our knowledge, the only paper that discusses the relationship between a manufacturer and a maintenance contractor is written by Ashgarizadeh and Murthy [2]. They use the principle of the Stackelberg game, assuming that the contractor is the leader and the manufacturer is the follower. Their goal is to obtain an equilibrium solution by optimizing the contractor's profit when the manufacturer's decision process can be anticipated. Consequently, channel coordination is neither considered nor accomplished.

In this paper, we follow the principle of channel coordination to discuss the issues in designing maintenance contracts. We consider a service chain consisting of a manufacturer and a maintenance contractor. The objective is to develop coordination strategies to ensure the optimal performance of the chain and a win-win situation for both the manufacturer and the contractor. It is assumed that the manufacturer has a deteriorating process and considers using an outside contractor for performing two types of maintenance: preventive and corrective. The contract between the two parties involves a fixed payment from the manufacturer to the contractor and a requirement that the contractor perform periodic preventive maintenance and necessary corrective maintenance procedures when the process breaks down. The manufacturer's objective directly relates to the average time that the process is in operation (uptime) while the contractor aims at reducing the cost associated with the maintenance activities. We develop two separate decision models for the manufacturer and the contractor to decide their individual optimal maintenance policies. We also develop one model for a coordinated decision assuming the two parties are integrated into one. The three optimal policies are compared and analyzed, and based on the results, we propose three coordination strategies: the first one is based on cost subsidization, the second is based on a bonus paid according to the uptime, and the third is based on a bonus paid according to the uptime above a pre-determined target.

Please note that the proofs of all results and an extensive numerical analysis are available upon request. Please contact Hakan Tarakci at tarakci@mgmt.purdue.edu for further information.

MODEL

Consider a service chain consisting of a manufacturer and a maintenance contractor. We assume the manufacturer's process has an increasing Weibull failure rate function, $\lambda(t) = kwt^{w-1}$, where $w \geq 2$ is the shape parameter, and k is the scale parameter. Note that the Weibull distribution is commonly used to describe the failure mechanism of a process in the maintenance and reliability literature because it can model many distribution forms by using different values of k and w [28] [6]. In this paper, we assume that the shape parameter, w , is an integer value, which is a common assumption in reliability studies. Furthermore, we assume $w \geq 2$, so that the process has an increasing failure rate (IFR) in time.

Two types of maintenance activities are considered by the manufacturer: preventive maintenance and corrective maintenance. Preventive maintenance (PM) is performed periodically to avoid costly repairs and distraction of production caused by process breakdowns. We use T_p and C_p to denote the average time and cost required to perform a preventive maintenance, respectively. It

is assumed that preventive maintenance overhauls the process and restores the failure rate to the original (best) state.

Corrective maintenance (CM) is performed when the process breaks down. We use T_r and C_r to denote the average time and cost required to perform a corrective maintenance, respectively. We assume corrective maintenance merely restores the process back to operation, and the deterioration of the process continues during corrective maintenance. Under this assumption, the process is restored to the condition it would be without breakdown and corrective maintenance. This assumption is used to simplify our analysis and is valid when T_r is relatively small or a corrective maintenance involves, for example, replacing minor components, while the rest of the process is not stopped. Furthermore, we also assume that preventive maintenance will take place if there is a corrective maintenance in process near the end of the cycle and the two types of repairs coincide.

The manufacturer considers outsourcing the maintenance functions to an outside contractor. The arrangements (contract) to be determined between the two parties are the schedule of preventive maintenance and the manufacturer's payment to the contractor for the service. Let T be the preventive maintenance interval defined as the time between the end of a PM and the beginning of the next one, and P the unit time payment to the contractor. In this paper, we assume P to be fixed; i.e. it is an exogenous parameter. The maintenance contractor is responsible for performing preventive maintenance periodically according to the schedule and necessary corrective maintenances whenever the process breaks down.

We assume that the net revenue of the manufacturer, after taking into account the production related costs, is R per unit time when the process is in operation. In order to determine the unit time profit for the manufacturer, we define a cycle as the time between two successive preventive maintenances. The length of a cycle is given as $T + T_p$. Under the Weibull failure rate function, for a given t value, the expected number of breakdowns in the time interval $[0, t]$, denoted by $M(t)$, is given by [3] [22]: $M(t) = k t^w$. As a result, the expected uptime of the process in a cycle is $T - M(T)T_r$, and the expected uptime level (the expected uptime per unit time) is given by $U(T) = (T - M(T)T_r)/(T + T_p)$ and the expected profit per unit time for the manufacturer is given by $\Pi_m(T) = R U(T) - P$. Let T_m^* maximize the manufacturer's profit.

Because the total expected cost in a cycle is $C_p + C_r M(T)$, the average maintenance cost per unit time is given by $C(T) = (C_p + C_r M(T))/(T + T_p)$, and the expected unit time profit for the contractor is given by $\Pi_c(T) = P - C(T)$. Let T_c^* maximize the contractor's profit.

It is clear that the manufacturer's objective is the maximization of the process' expected uptime, but the contractor's objective is the minimization of the total expected maintenance cost. Consequently, an agreement may not be reachable between the two parties. The total expected profit for the manufacturer and the contractor, or the service chain, as a function of T is given by $\Pi(T) = R U(T) - C(T)$. Let T^* maximize the system's profit.

Lemma 1. Define $g(T) = k[(w - 1) T^w + w T_p T^{w-1}]$. Then, $g(T_m^*) = T_p / T_r$, $g(T_c^*) = C_p / C_r$ and $g(T^*) = (RT_p + C_p)/(RT_r + C_r)$.

It is straightforward to verify that $g(\cdot)$ is an increasing function of T . Consequently, although closed-form solutions for T_m^* , T_c^* , and T^* are not available, a simple numerical search procedure can be used to find the optimal solutions.

Lemma 2. The relationships among T_m^* , T_c^* , and T^* are given by (i) $T_c^* = T_m^* = T^*$ if $C_p/C_r = T_p/T_r$, (ii) $T_c^* > T^* > T_m^*$ if $C_p/C_r > T_p/T_r$, and (iii) $T_c^* < T^* < T_m^*$ if $C_p/C_r < T_p/T_r$.

It is straightforward to show that $U(T)$ is concave in T . Because T_m^* is the value that maximizes $U(T)$, using Lemma 2, we can state that $U(T_c^*) \leq U(T^*) \leq U(T_m^*)$. This suggests that the manufacturer may consider an incentive to induce the contractor to select the preventive maintenance interval that increases the uptime level and optimizes the profit of the service chain. Using the cost ratio, C_p/C_r , and the time ratio, T_p/T_r , we know the relationships among the optimal preventive maintenance intervals of the manufacturer, the contractor, and the service chain. These relationships are the basis for developing coordination strategies discussed in the next section. For example, if $C_p/C_r > T_p/T_r$, then $T_c^* > T^* > T_m^*$. In this case, the coordination effort will be focused on an incentive to induce the contractor to reduce her preventive maintenance interval.

COORDINATION MECHANISMS

In practice, it is rare that the cost ratio, C_p/C_r , is exactly equal to the time ratio, T_p/T_r . When these two ratios are not equal, the efficiency of the service chain can be improved by coordination efforts. A question arises about how to develop a mechanism that ensures a cooperative setting and how to allocate the extra profit generated from coordination. There are actually many possible coordination methods. One of the more direct ones is for the manufacturer to give an incentive to induce the contractor to choose T^* as the optimal solution. It is important to point out that, for a coordination mechanism to be implementable, both parties should receive benefits through coordination. In this section, we discuss three possible methods for achieving channel coordination, including cost subsidization, uptime bonus, and a combination of uptime target and bonus, assuming that in each of these three cases, the contractor is the one choosing the preventive maintenance schedule. We also assume that all the cost and process parameters are known by the two parties.

Cost Subsidization

If $T = T_c^* > T^*$, the manufacturer may subsidize a portion of the PM cost of the contractor to reduce the contractor's optimal preventive maintenance interval from T_c^* to T . This means, the manufacturer pays the contractor ΔC_p each time the contractor performs preventive maintenance. The effective cost of PM to the contractor is then given by $C_p' = C_p - \Delta C_p$. Using Lemma 1, the contractor's optimal PM interval, T_c^* , satisfies $g(T_c^*) = C_p'/C_r$. For the desired result, T_c^* should also satisfy $g(T_c^*) = (RT_p + C_p)/(RT_r + C_r)$ to achieve channel coordination. Consequently, C_p' is given by $C_p' = (C_r(RT_p + C_p))/(RT_r + C_r)$ and $\Delta C_p = C_p - C_p'$. Since the effective preventive maintenance cost is lower under the arrangement, the contractor's expected profit is higher. As for the manufacturer, the additional revenue from the increase in uptime must be greater than the subsidizing payment he will make to the contractor. In other words, for the manufacturer to increase his expected profit, we must have: $R[U(T^*) - U(T_c^*)] \geq (\Delta C_p)/(T^* + T_p)$. Unfortunately, we cannot always show that this condition holds. For instance, a low value of R would violate

the requirement. However, in practice, the above condition would generally hold. Finally, please note that if $T_c^* < T^*$, channel coordination can be achieved by subsidizing the contractor for the corrective maintenance cost. The results and conditions for a win-win coordination in this case are similar to those of the preventive maintenance cost subsidization case.

Uptime Bonus

The second incentive method is in the form of a bonus payment for the uptime level that the contractor achieves. The contractor receives a bonus of B proportional to the uptime level achieved. Thus, the profit of the contractor can be given by $\Pi_c'(T) = P - C(T) + B U(T)$, where B is a positive decision variable to be chosen by the manufacturer. Using the bonus scheme, we would like the contractor to choose T^* as the preventive maintenance time interval. After some algebra, we can show that B must be equal to R . Therefore, in such an incentive setting, the contractor will cooperate only if the manufacturer pays her the entire revenue, R . In such a case, the manufacturer's profit will be $(-P)$. The policy does not lead to a desired win-win situation, because the manufacturer has a negative profit. Hence, if the bonus payment is made for every unit of uptime, coordination is not possible unless additional profit mechanisms are considered.

Uptime Target Level and Bonus

The third method is also based on a bonus, but the bonus is only given when the uptime level is above a target set by the manufacturer. Let τ denote the target uptime level, and B the per unit time bonus for the contractor's uptime above the target. Under this incentive plan, the contractor's profit becomes $\Pi_c'(T) = P - C(T) + B[U(T) - \tau]^+$, where $[x]^+ = \max\{x, 0\}$. Applying some algebra, we can show that we need $\tau < U(T^*)$ and $B = R$ for $T = T^*$ as desired. Now, please note that as τ increases, the manufacturer obtains a larger share of the additional profit from coordination. We would like to find the range (the upper and lower bounds) for τ so that the two parties benefit from the coordination efforts. The lower bound is set to ensure the manufacturer is not worse-off and the upper bound is set to guarantee the contractor is not worse-off compared to the pre-coordination setting. We find that the lower bound is given by $\tau_1 = U(T_c^*)$ and that the upper bound is given by $\tau_2 = U(T^*) - \{[C(T^*) - C(T_c^*)] / R\}$. Hence, as long as $B = R$ and τ is set within the lower and upper bounds, we can achieve a win-win channel coordination as desired.

CONCLUSION

We analyzed maintenance outsourcing contracts in this paper. The manufacturer wants to maximize the uptime of the system, whereas the contractor aims to minimize maintenance costs. These different goals lead to different optimal maintenance policies for the two parties. To increase the efficiency of the system, we propose coordination between the two parties. To this end, we provided three coordination mechanisms. We showed that one works all the time, one works most of the time and one never works as a win-win incentive mechanism.

REFERENCE

Please contact Hakan Tarakci at tarakci@mgmt.purdue.edu for a list of references.