THE DESIGN OF EFFECTIVE MAINTENANCE OUTSOURCING CONTRACTS

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ABSTRACT

Recent developments in maintenance planning and management demonstrate that the establishment of optimized maintenance policies may drastically improve the performance and reduce the operating cost of facilities. However maintenance activities are typically outside of the core business of production facilities, hence enterprises often fail to catch the opportunities that may originate by properly optimized management strategies. A strategic maintenance management should hence encompass the possibility of outsourcing maintenance activities to ensure the necessary perfomance of production systems, while allowing enterprises to concentrate their resources on their core activities. In order to be effectively undertaken an outsourcing strategy must be supported by a proper performance oriented contract. The present paper aims to provide an adequate methodology to address such issues and to define a framework for the definition of the relevant contract variables such as availability levels, penalty policies, rewards and service cost. The methodology here proposed is based upon the evaluation of the expected profit function of both the outsourcer and the provider, by performing a trade-off analysis on the basis of the transaction costs.

INTRODUCTION

Maintenance activities have recently gained a substantial interest due to the strategic management opportunities arisen in the market. Recent developments in maintenance planning and management demonstrate that the establishment of optimized maintenance policies may drastically improve the performance and reduce the operating cost of facilities. However maintenance activities are typically outside of the core business of production facilities, hence enterprises often fail to catch the opportunities that may originate by properly optimized management strategies. In such context market opportunities have arisen for enterprises that make of advanced maintenance management their core business, thus offering their services to companies willing to outsource. A strategic maintenance management may hence encompass the possibility of outsourcing maintenance activities to ensure the necessary availability of production systems, while allowing enterprises to concentrate their resources on their core activities, thus originating economic, financial and operative advantages. As a matter of fact, however, many enterprises are adverse to outsourcing strategies: this is frequently due to inadequate or unbalanced contracts.

In order to be effectively undertaken an outsourcing strategy must be supported by a proper performance oriented contract. Although much interest has been focused upon the determination of optimal maintenance policies, not much attention has been focused to the importance of a proper establishment of contract variables such as performance level costs, penalties and incentives. While the problem of determining the optimal maintenance policy may be a major concern for service provider, the determination of optimal contracting conditions regards both the contractors and may be essential for a successful agreement.

The present paper aims to provide an adequate methodology to address such issues. An overview of the different outsourcing contracts is hence preliminary provided, focusing upon the most significant contractual aspects. The analysis finally focuses upon Global Service (GS) contracts which are particular contracts which involve two contractors, an “outsourcer” and a “provider” in a performance oriented agreement. The maintenance service provider freely organizes and manages specific maintenance operations upon the outsourcer’s equipment in order to ensure the pre-established performance level. The establishment of such performance levels involves the definition of specific, Service Level Agreements (SLAs) which in turn involves the definition of suitable measurable indicators (Key Performance Indicators, KPI). SLAs typically have penalties associated with not meeting the specified performance levels, and sometimes have rewards when performance levels are outperformed. SLAs hence must be very carefully defined, and must be agreed between the outsourcer and the service provider at the contracting phase. Frequently, a Maintenance Information System must also be implemented to allow both the outsourcer and the provider to monitor and control the performance level achieved at each period, thus allowing the evaluation of penalties and rewards.

According to the considerations reported above, it is clear that the contracting activity for a global service is a critical task that must be accurately performed. The contract variables in fact coordinate the relationship between the outsourcer and the provider whose individual profit functions are typically conflicting. The relationship between contractors must hence be properly coordinated in order to achieve a cooperation strategy to ensure a global optimal result. Such coordination strategy clearly depends upon the selection of appropriate contract variables.

In order to properly coordinate an outsourcing contract the individual profit functions of the contractors must be calculated and penalties, rewards and performance levels must be properly established in order to ensure the optimal overall performance of the system. To accomplish such objective the possibilities of establishing a win-win strategy between the contractors must be analyzed.
In the present paper a coordination model is presented which involves the evaluation of the individual profit functions of both the contractors, taking into account fixed and variable maintenance costs (for the service provider), as well as system downtime costs (for the outsourcer). Such costs clearly depend upon the maintenance policy and the service level (system availability) established. Due to the stochastic nature of the relevant maintenance parameters the related risk must be properly distributed between the contractors, by means of suitable penalty and reward policies. Aim of the paper is to provide a framework for the definition of the relevant contract variables such as availability levels, penalty policies, rewards and service cost.

MAINTENANCE POLICIES AND COSTS

Maintenance is typically perceived as any activity carried out in order to repair any equipment that has failed, or to restore to its favorable operating condition when performance decreases due to the wear. Over the years, many maintenance strategies have been formulated to overcome the problem equipment breakdown. Some of the common maintenance strategies are given below.
Corrective Maintenance
Corrective maintenance consists of all the activities of repairing, restoration or replacement of components, required to re-establish the operating condition of equipment after a failure. This is one of the earliest maintenance program being implemented in the industry and still it is the only possible strategy when no information is given about the failure rate. This approach to maintenance is totally reactive since the maintenance intervent is triggered by the system fault. This strategy hence has no scheduled tasks and the corrective maintenance activity is required to correct a failure that has occurred.
Preventive Maintenance
This is a time-based maintenance strategy where on a predetermined periodic basis, equipment is taken off-line, some pre-established maintenance tasks are performed and the equipment is then put back on-line. Under this maintenance strategy, replacing, overhauling or remanufacturing an item is done at a fixed intervals regardless of its condition at the time. Each maintenance action may re-establish the state of the equipment "as well as new" thus resulting in a perfect maintenance action, or it may establish an imperfect state which means the machine is fixed to a condition that is worse than the new component. Complex maintenance models may establish a relation between the time required to perform the maintenance action and the availability level reached (Jaturronnatee et al 2006). Although this is a well-intended strategy, the process can be very expensive if the maintenance interval is too short or too long compared to the intrinsic failure characteristics of the machinery. The frequency and the duration of preventive maintenance tasks also influences the total availability of the system, hence the determination of a correct maintenance plan which optimizes system costs or system availability is crucial.
Predictive Maintenance
Predictive maintenance is a condition-based approach to maintenance. The approach is based on measuring of the equipment condition in order to forecast the occurrence of the next failure. Maintenance actions to avoid the occurrence of failures are then established and undertaken. Predictive technologies (i.e. vibration analysis, infrared thermographs, ultrasonic detection, etc.) are utilized to determine the condition of equipments, and to decide on any necessary repairs. Statistical forecasting techniques based upon equipment performance monitoring are also adopted to determine the maintenance tasks to be performed. This approach is more economically feasible strategy as labours, materials and production schedules are used much more efficiently. The main drawback however is that it is frequently difficult to find a reliable correlation between a measured parameter and the failure characteristic of the equipment.
Proactive Maintenance
Unlike the three type of maintenance strategies which have been discussed earlier, proactive maintenance can be considered as another new approach to maintenance strategy. Dissimilar to preventive maintenance that is based on time intervals or predictive maintenance that is based on condition monitoring, proactive maintenance concentrate on the monitoring and correction of root causes to equipment failures. The proactive maintenance strategy is also designed to extend the useful age of the equipment to reach the wear-out stage by adaptation a high mastery level of operating precision.
Maintenance costs
The main concern when establishing a maintenance policy for a specified equipment is to achieve cost efficiency providing the adequate availability of the system. In recent years, there is a growing concern on the subject of higher maintenance cost and maintenance productivity. Typically, maintenance cost can be divided into two main groups. The first group referred as direct costs are easy to justify and to report. These direct costs consist of items such as labour, materials, services, etc. The other group of maintenance costs is hidden costs or indirect costs which are harder to measure. These hidden costs of maintenance involve for example breakdowns and unplanned plant shutdown, excessive set-up, changeovers and adjustments, idling and minor stoppages, running at reduced productivity, start-up losses, quality defects, etc. For each maintenance action performed on a generic equipment the Total Cost for Individual repair (TCI) can be calculated as:

$$TCI = C_{sp} + C_m + C_l + C_p$$

Where C_{sp} = cost of the spare parts; C_m = cost of materials; C_l = cost of labour; C_p = cost of downtime (i.e. cost of lost production).

In order to evaluate the individual cost of a generic maintenance action, the above listed cost elements should be evaluated. A complex system may undergo different failure conditions (Failure Modes), each one requiring a specific corrective maintenance action. In order to evaluate the cost elements given before, hence, a preliminary Failure Mode and Effect Analysis (FMEA) should be performed. In addition some of the cost elements, such as the cost of spare parts, are fixed and strictly fault-dependent, while some others are time-dependent. In particular the cost of labour for a generic maintenance task can be expressed as a function of the Mean Time To Repair (MTTR):

$$C_l = C_h \cdot MTTR$$

Being MTTR the average time required to perform the maintenance activity and C_h =maintenance labour cost per hour. The cost of downtime, as lost production, can be simply (detailed evaluation of downtime cost is outside of the scope of the paper) evaluate as:

$$C_p = \frac{MTTR}{T_c} \cdot p$$

With p= marginal revenue and T_c= cycle time.

The Expected annual cost of a generic maintenance policy can hence be calculated as:

$$TEMC = MDT\left[C_h + \frac{p}{Tc}\right] + \sum_{i=1}^{N}\left(C_{spi} + C_{mi}\right)$$

Where MDT is Mean Expected Downtime incurred in 1 year, and N is the total number of maintenance actions performed each year.

COORDINATION AND GLOBAL SERVICE CONTRACTS

A contract is defined as an agreement by which one or several economic agents commit themselves to one or several others to giving, doing or not doing something. The contract as an inter-individual coordination mechanism can be analyzed along two different approaches (Debande et al, 1996). The agency theory approach (Jensen and Meckling 1976) aims at solving the coordination problems between two contractors, a principal and an agent, within the framework of a bilateral relation when, on the one hand, the agent can choose the level of his commitment, and, on the other hand, his actions affecting the welfare of both parties cannot be observed by the principal actor. This literature (Guesnerie & Laffont, 1984a; 1984b, for instance) aims at defining optimal incentive contracts between economic agents holding unequal information. The transaction costs approach (Williamson, 1975; 1985) rests on the notion of the limited rationality of the agents. The transaction costs are the costs of coordinating the organization in its interactions with the outside environment and in its interactions between actors inside the organization. This analysis aims at explaining the organization structure, the control and management procedures which allow coordination of agent activities at the lowest cost.

Outsourcing consists of two parties, the user company and the subcontractor, who have conflicting interests. Taking into account the interests of both parties, coordination is necessary. The reason is that by coordination the outsourcing supply chain can achieve the maximal profit possible. With a proper contract the total profit can be split between the user company and the subcontractor such that both parties are better off than when the outsourcing supply chain is not coordinated. In other words, with a coordinating contract both parties can ‘make a bigger pie’, and share it in such a way that each gets a bigger piece.

A contract determines the legal parameters of the service and the responsibilities of each part and must pay attention to the combined value. The issue that is addressed in this paper is how to coordinate the contractors to achieve global system optimality. In order to achieve such condition the utility functions of each contractor must be taken into account. If the space of all possible contracts can be explored exhaustively, and the overall utility function for different possible contracts is linear, with a single optimum in the utility function for each agent, the system can be easily optimized. In such a context, the reasonable strategy is for each agent to start at its own ideal contract, and concede, through iterative proposal exchange, just enough to get the other part to accept the contract. When the utility functions are simple, it is feasible for one agent to infer enough about the opponent’s utility function through observation to make concessions likely to increase the opponent’s utility. Real-world contracts, however, are generally much more complex, consisting of a large number of inter-dependent issues.

A Global Service maintenance contract involves two contractors, an “outsourcer” and a “provider” in a performance oriented agreement. The outsourcer contracts with the service provider a defined scope of work, and the service provider charges the outsourcer a fee. In exchange for the fee, a service is provided at a guaranteed quality level. Global Service contracting for maintenance management involves the outsourcer to freely establish the most suitable maintenance strategy according to the failure characteristics of the equipment maintained. Such strategy may be heterogeneous, encompassing corrective, preventive, and condition based maintenance, as well as spare parts management.

Global Service contracts hence rely upon the establishment of a certain performance level and a service fee. Typically the outsourcer establishes the desired performance level and the vendor establishes the corresponding fee. The definition of performance levels involves the specific, Service Level Agreements (SLAs) which in turn involve the establishment of suitable measurable indicators (Key Performance Indicators, KPI). SLAs typically have penalties associated with not meeting the specified performance levels, and sometimes have rewards when performance levels are outperformed. SLAs hence must be very carefully defined, and must be agreed between the outsourcer and the service provider at the contracting phase. Frequently, a maintenance information system must also be implemented to allow both the outsourcer and the provider to monitor and control the performance level achieved at each period, thus allowing the evaluation of penalties and rewards. In such case the investment should be properly shared. For such reasons, GS contracting for maintenance outsourcing is generally troublesome, but it has a drastic influence upon the success of the contract. As a result of the contracting phase the following fundamental contract parameters must be established.

Duration of the contract.

The duration of the contract defines the amount of time contract is enforced. Depending upon the intrinsic failure characteristics of the equipment maintained the duration of the contract may be a critical issue for the vendor to establish the suitable maintenance policy since equipments degrade with age and/or usage. The contract must also define the terms and conditions at which both parties may prematurely solve the contract.

Services, place of performance, initial inspection.

Depending on the type of contract, the maintenance services are derived from the performance description. The details of the nature and scope of these services are based on the vendor's work plans which can be modified and adapted from time to time at his own discretion to ensure that requirements are met. In general any substances used to clean and maintain the instruments, along with spare parts, exchanged parts and wearing parts only form part of the scope of the maintenance contract if they are explicitly included. In as far as possible and reasonable, reconditioned exchanged parts instead of new spare parts usually can be used at the vendor's discretion. The ownership of exchanged parts is transferred to the vendor. Unless otherwise agreed in the maintenance contract the services will be performed at the location where the equipment is being used at the time the contract is concluded. If the location is changed by the outsourcer he shall inform the vendor of the transfer. If the vendor approves the transfer the maintenance services will be performed at the new location. For instruments that have not been maintained regularly by the vendor since they were first commissioned, or for which maintenance has been interrupted for more than one maintenance interval, the vendor may reserve the right to carry out an initial inspection at the outsourcer's expense.

Performance requirements.

The performance requirements can involve several measures such as the upper limit on the number of failures over the lease period, the time interval between successive failures, the time to repair each failure and so on. When these are not met the vendor incurs penalties which must be explicitly stated in the contract.

Not included services.

The GS contract must also define the services that are outside of the agreement. Such services will only be performed by the vendor on the basis of a separate contract and at a separate charge. A typical issue in such case is the management of spare parts which may be charged to the outsourcer or to the vendor. Are in any case charged to the outsourcer the exchange parts which are necessary, not as a result of natural wear and tear, but as a result of external influences, such as improper use, operation or other interventions by third parties, as well as other circumstances that cannot be attributed to the vendor. Are also charged to the outsourcer all the exchange expenses of instrument-specific consumables, unless this takes place within the context of maintenance without significant additional cost.

Maintenance personnel.

In GS contracts typically the outsourcer requires the maintenance tasks to be performed by trained and expert personnel. For such reason the vendor may be entitled to subcontract the maintenance work to third parties, however, such subcontracting shall not release the vendor from his contractual obligations towards the outsourcer.

*Maintenance times***.**

Being GS a performance oriented contract it does not necessarily include time obligations for the vendor. The maintenance intervals are in fact derived from the performance, unless they are laid down in the contract. The time when the maintenance work will be performed shall be agreed upon by the parties. The vendor shall agree with the contractor the preferably maintenance periods. If the outsourcer suffers damage and he can prove that it is the result of a delayed performance, the outsourcer shall be entitled to demand compensation up to the price of the maintenance work that was not performed on time.

Payment.

As payment for the services, the vendor may be entitled to charge, depending on the type of agreement, a flat maintenance fee for each date or specific period of maintenance work. If the maintenance personnel are held up in the performance, the waiting times may also be charged to the outsourcer. The outsourcer shall also bear any additional costs incurred if, the maintenance work cannot be performed or cannot be performed in full within the agreed time for reasons attributable to him. The GS contract typically contains positive and negative incentives. A positive incentive is one involving rewards. If the contractor exceeds the minimum levels of performance, a monetary reward is paid. A negative incentive is a penalty imposed for failing to meet a contractual requirement. The type of negative incentive intended here is related to a specific performance requirement, such as availability. The presence of a negative incentive and a positive incentive will ensure that the performance requirements are met. However, the negative incentive provides no motivation for exceeding the requirement.

Information/Cooperation duties.

In order to allow the vendor to perform the required maintenance operations the outsourcers shall make the equipments available to the vendor's maintenance personnel and representatives at the agreed time. The outsourcer shall make available for the duration of the maintenance work all the tools and the appropriate support staff to operate the instruments and support the maintenance personnel. The information required about the instrument to be maintained shall be passed on and the associated documents made available to the maintenance personnel and representatives. The outsourcer shall inform the maintenance personnel of any peculiarities and problems that have appeared in relation to the instrument to be maintained without being asked for such information.

PERORMANCE MEASURES

A key issue to achieve the optimum benefit from maintenance outsourcing is to track the performance level related to the maintenance policy established.

For such reason effective performance measurements must be established and clearly agreed upon. Tracking the level of service is a critical task to achieve effective maintenance outsourcing advantages.

In the maintenance partnership scenario in fact, performance guarantees and continuous improvement goals provide greater control over maintenance results and assure production goals are being achieved.

When maintenance is outsourced, the first question is how to measure performance. To determine the "best" measure, one must first determine the requirements of the system in question. Furthermore for plants running, on a 24 hour per day, 365 day per year basis, high availability is absolutely essential.

Given that essential requirement, one of the measures for contractor maintenance should be derived from availability. The other should be based on economic considerations. According to the production objectives and the plant uptime required a suitable set of indicators (KPI, Key Performance Indicators) must be established in order to obtain an effective performance measure (Forni et al., 2003).

Some of the most common performance indicators employed in maintenance outsourcing contracts are given below.

Availability-related requirement.

Even with adequate redundancy, system failures will eventually occur. The number of system failures will be determined by several factors such as reliability of all components and equipment, use of redundancy, effectiveness of maintenance, and so forth. When a failure does occur or when a preventive maintenance action is performed, the job of maintenance is to restore the system to full operation as quickly as possible. The downtime related to the maintenance task will reduce the overall availability of the system which turns into costs for the outsourcer.

Availability related measures will hence be enforced. Such measures may be the maximum downtime, maximum time to restore system, and turn around time.

Maximum downtime.

Specifying the maximum downtime (MaxDT) is specifically intended to limit the periods of non-operation. A stated period of operation must be stipulated for a MaxDT requirement. For facilities, the requirement would normally be stated for each year of operation.

Maximum time to restore system.

Related to MaxDT is Mean Time to Restore (MTTRS). MTTRS relates to the maximum time it will take to restore the system from any one failure event. In other words, although the parameter MDT limits the downtime over a one year period, it is statistically possible for one failure event to take a long downtime to correct. Such a long downtime for the single action is usually unacceptable. MTTRS limits the downtime that results from any single system failure.

Turn around time.

Only a limited number of spares can be bought, especially at the equipment or "box" level. Consequently, when a failed piece of equipment must be removed and replaced at the facility level and repaired at a field or depot level, the length of time it takes to return the equipment to the spares supply is important. The shorter the turn around time (TAT), the fewer the number of spares that need be purchased, all other factors remaining constant.

Economic requirement.

Given fiscal realities and limited funding, economic considerations are also important. It is assumed that the contractor who can demonstrate in the proposal that they can provide the stipulated maintenance at the required level of performance at the lowest cost will be awarded the contract. "Cost" should be more than the price of the contract. The overall life cycle costs that will be incurred over the life of the contract should be considered.

Notation

L	duration of the contract
T	preventive maintenance interval
σ	performance measure
C(σ)	maintenance cost incurred by the vendor
I(σ)	outsourcer's revenue
W(σ)	vendor's fee
R(σ)	reliability corresponding to performance level σ
F(t)	failure distribution function
f(t)	failure density function associated with F(t)
MDT(T)	mean expected down-time
$MTTR_f$	mean time to repair of corrective maintenance tasks
$MTTR_p$	mean time to repair of preventive maintenance tasks
MTBR	mean time between replacement
C_h	maintenance labour cost per hour
$C_p = MTTR_p \cdot C_h$	cost of preventive maintenance
$C_f = MTTR_f \cdot C_h$	cost of corrective maintenance
t	transaction cost
e	performance monitoring cost
Π_o	outsourcer's profit
Π_v	vendor's profit
p	product marginal profit
Tc	cycle time
Av (σ)	availability of the system

THE MODEL

The need for coordination arises each time two or more subjects with conflicting objectives are involved in the same economic opportunity. Assuming a rational behaviour, each subject pursues his own maximum utility objective, thus preventing the system to achieve the maximum global utility. In other words, by properly coordinating the outsourcing contract, the system can achieve the maximal profit possible. Then, with a proper contract the total profit can be split between the outsourcer and the subcontractor such that both parties may benefit of the higher global profit.

In order to achieve coordination a typical approach is to consider the “centralized” solution and the “decentralized” solution, analysing in the first case the global profit of the system, and in the second case the individual utilities of the contractors. The next step consists in modifying the contractors' utility function in order to align their strategies and achieve the maximum system profit. Once this analysis has been performed, coordination may be achieved by establishing a suitable contract which modifies the individual utilities by adopting revenue-sharing procedures.

To achieve coordination a contract must:

(1) achieve a system-optimal level,

(2) arbitrarily split the profit between the contractors.

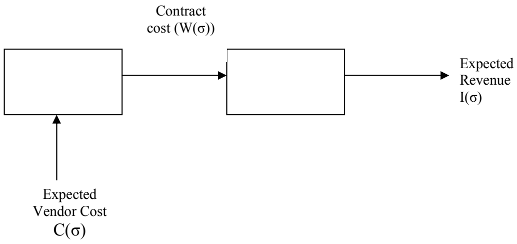
It obviously depends on the specific form of the contract, as it will be proven that the simple form of a fixed payment, will not induce the system to reach its optimal level.

In order to achieve coordination, a GS contract must be linked to a performance measure σ, and according to the performance level requested by the outsourcer the vendor should establish the corresponding reward W. Being L be the duration of the contract, C(σ) the maintenance cost incurred by the vendor, I(σ) the outsourcer's revenue corresponding to the performance level σ, the vendor and the outsourcer's profit functions are given by the following equation (1) and (2):

$$\Pi_o(\sigma, p) = I\ (\sigma) - t - e - W(\sigma) \qquad (1)$$

$$\Pi_v(\sigma, p) = W(\sigma) - C(\sigma) \qquad (2)$$

Let us also assume that t (transaction costs) and e (monitoring costs) are fixed, we will, therefore, drop our references to these variables (Bryson et al, 1999, 2000, 2003). The model will be thus simplified as given in the figure below.



$$\Pi_o = I(\sigma) - W(\sigma)$$
$$\Pi_v = W(\sigma) - C(\sigma)$$
$$\Pi_{TOT} = R(\sigma) - C(\sigma)$$

Figure 1: *Basic coordination scheme*

A simple model for the outsourcer's revenue function is to consider the outsourcer's revenue related to the system availability *Av*. The application to a production plant which produces a product with marginal revenue *p* and cycle time *Tc* would thus be:

$$I(\sigma) = \frac{Uptime(\sigma)}{Tc} p = Av(\sigma) \frac{L}{Tc} p$$

On the other hand the profit of the vendor is related to his reward corresponding to the performance level σ and the related maintenance cost C(σ). The cost for the vendor ultimately depends upon the maintenance policy adopted. The utility of the vendor increases as maintenance costs decrease, hence the establishment of an effective maintenance policy becomes a crucial issue in such contracts.

GLOBAL SERVICE CONTRACTS WITH PREVENTIVE MAINTENANCE POLICIES

In order to give an explicit formulation of the above equations, an assumption must be made for the maintenance policy adopted by the vendor. In the present paper the maintenance policy considered is a standard preventive maintenance policy with perfect repairs as described above. In such case the availability *(Av (σ))* of the system is related to the intrinsic fault probability function of the system and the average repair time necessary to perfectly replace the system condition "as good as new" when either a failure occurs (a corrective maintenance (CM) task is required) or a preventive maintenance (PM) is performed. The mean time to repair when a corrective or a preventive maintenance occurs are respectively: $MTTR_f$ $MTTR_p$. According to such considerations the expected revenue of the outsourcer as a function of the system availability (Rausand, and Høyland, 2003) is:

$$MDT(T) = \left[MTTR_p \int_T^{\infty} f(t)dt + MTTR_f \int_0^T f(t)dt \right] =$$
$$= MTTR_f \cdot F(T) + MTTR_p \left[1 - F(T)\right]$$

$$MTBR(T) = \int_0^T [1 - F(t)]dt + MTTR_p \int_T^{\infty} f(t)dt + MTTR_f \int_0^T f(t)dt =$$
$$= \int_0^T [1 - F(t)]dt + MDT$$

$$Av(T) = 1 - \frac{MDT(T)}{MTBR(T)} =$$
$$= 1 - \frac{\left[MTTR_p \int_T^{\infty} f(t)dt + MTTR_f \int_0^T f(t)dt \right]}{\int_0^T [1 - F(t)]dt + MTTR_p \int_T^{\infty} f(t)dt + MTTR_f \int_0^T f(t)dt};$$

The outsourcer profit, function of the system availability is:

$$\Pi_o = I(\sigma) - W(\sigma) = Av(T) \frac{L}{Tc} p - W(\sigma)$$

$$\Pi_o = \left[1 - \frac{\left[MTTR_p \int_T^{\infty} f(t)dt + MTTR_f \int_0^T f(t)dt \right]}{\int_0^T [1 - F(t)]dt + MTTR_p \int_T^{\infty} f(t)dt + MTTR_f \int_0^T f(t)dt} \right] \frac{L}{Tc} p - W(\sigma)$$

Which ultimately is a function of the intrinsic failure rate of the system, the preventive maintenance interval and the mean time to repair for corrective and preventive maintenance.

The vendor profit is related to the cost of the preventive maintenance policy, which again is a function of the intrinsic failure rate of the system, the preventive maintenance interval and the mean time to repair for corrective and preventive maintenance. The costs associated with failures of equipment are typically higher than costs associated to preventive maintenance. This implies that the optimal PM actions need to be determined through a proper trade-off between the CM and PM costs. For a preventive maintenance policy and a given interval T, the total cost of maintenance is:

$$C(T) = \frac{C_p}{T} R(T) + \frac{C_f}{T} \left[1 - R(T)\right]$$

Being C_p the intervention cost of preventive maintenance and C_f the intervention cost of the corrective maintenance, the vendor's profit function is given by the following eq. (3):

$$\Pi_v = W(\sigma) - \left(\frac{C_p}{T} R(T) + \frac{C_f}{T} [1 - R(T)] \right) L \quad (3)$$

Which is a function of the reward, the intrinsic failure rate of the system, the preventive maintenance interval and the cost of a corrective and a preventive maintenance action.
In order to exploit the opportunities for coordination, the system profit must be determined.

$$\Pi_{tot} = \Pi_o + \Pi_v = I(\sigma) - C(\sigma)$$

$$\Pi_{tot} = \left[1 - \frac{\left[MTTR_p \int_T^{\infty} f(t)dt + MTTR_f \int_0^T f(t)dt \right]}{\int_0^T [1 - F(t)]dt + MTTR_p \int_T^{\infty} f(t)dt + MTTR_f \int_0^T f(t)dt} \right] \frac{L}{Tc} p +$$
$$- \left[\frac{C_p}{T} R(T) + \frac{C_f}{T} [1 - R(T)] \right] L$$

Vendor-Outsourcer coordination is achieved when global system profit is maximized. It can be easily seen that a simple fixed fee contract does not allow achieving coordination. If in fact W(σ) is a constant, and both the vendor or the outsourcer pursue a strategy to maximize their own personal profit function, the outsourcer profit is maximized when the following condition occurs:

$$\Pi_o^* \Rightarrow \frac{d}{dT} \left(1 - \frac{\left[MTTR_p \int_T^{\infty} f(t)dt + MTTR_f \int_0^T f(t)dt \right]}{\int_0^T [1 - F(t)]dt + MTTR_p \int_T^{\infty} f(t)dt + MTTR_f \int_0^T f(t)dt} \frac{L}{Tc} p - W \right) = 0$$

$$\frac{d}{dT} \left(1 - \frac{\left[MTTR_p \int_T^{\infty} f(t)dt + MTTR_f \int_0^T f(t)dt \right]}{\int_0^T [1 - F(t)]dt + MTTR_p \int_T^{\infty} f(t)dt + MTTR_f \int_0^T f(t)dt} \right) = 0$$

While the vendor profit is maximum when:

$$\Pi_v^* \Rightarrow \frac{d}{dT} \left[W - \left(\frac{C_p}{T} R(T) + \frac{C_f}{T} [1 - R(T)] \right) \right] = 0$$

$$\frac{d}{dT} \left(\frac{C_p}{T} R(T) + \frac{C_f}{T} [1 - R(T)] \right) = 0$$

While the Outsourcer pursues a maximum availability objective, the vendor pursues a minimum cost objective. If in a fixed price contract the outsourcer pays a fee W for performing at level σ*, but the vendor actually performs at level σ < σ*, then in the absence of any penalty the vendor increases his profit by (C(σ)-C(σ*)). Even increasing the value of W (i.e. the outsourcers raises the vendor's reward) will not have a positive effect upon the global system performance since it has no effect upon the optimal profit point of the vendor. Coordination hence cannot be achieved unless a proper revenue sharing contract is established which modifies the individual profit function of the vendor and the outsourcer. In order to achieve coordination hence a fixed fee contract cannot be employed, and proper incentive/penalty costs must be established as a function of the performance level achieved. A typical linear penalty may hence be in the following form:

$$W(\sigma) = k - a(\sigma^* - \sigma)$$

Where k = constant fee, a = penalty rate, σ* = penalty threshold.
In the contract considered if σ* = minimum availability allowed by the outsourcer:

$$\Pi_o = I(\sigma) - W(\sigma) = Av(T) \frac{L}{Tc} p - k - a[Av(T) - Av^*] =$$
$$= Av(T) \left[\frac{L}{Tc} p - a \right] + aAv^* - k$$

And by assuming:

$$\frac{L}{T_c} p = a \quad (4)$$

We achieve:

$$\Pi_o = aAv^* - k = const$$

Thus the total profit is:

$$\Pi_{Tot} = \Pi_o + \Pi_v = \Pi_v + const$$

In such case the vendor profit becomes an affine function of the total profit, hence, by maximizing his profit, the vendor will maximize total system profit. The outsourcer profit share is given by k. Thus, by adopting a linear penalty function and by defining the penalty rate according to equation (4) system coordination is achieved and profit can be arbitrarily shared.

NUMERICAL APPLICATION

In this paragraph a numerical application is proposed. The system failure has been modelled as a Weibull function with α=1000 and β=3,5. The cost of the planned maintenance task is C_p = € 4000, the cost of the unplanned maintenance is C_f = € 7000, L/Tc*p=100, $MTTR_f$= 50 h $MTTR_p$=20 h. The total maintenance cost per unit time is given in figure2

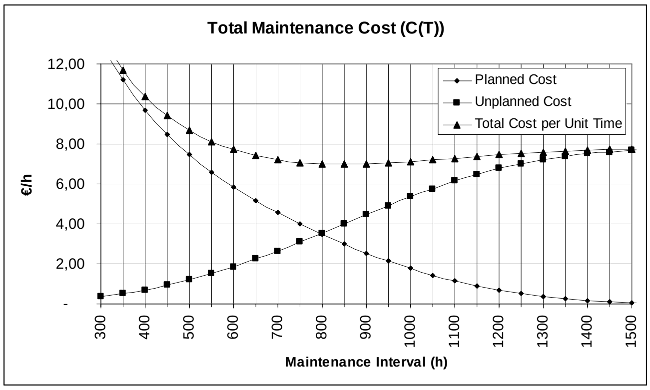


Figure 2: *Vendor's total maintenance cost per unit time*

The T* that achieves minimum maintenance cost is approx. 850 h with a total maintenance cost of 6,99 €/h.
The vendor profit function is:

$$\Pi_v = W(\sigma) - C(\sigma) = W - \left[\frac{C_p}{T} e^{-\left[\frac{T}{\alpha}\right]^{\beta}} + \frac{C_f}{T} \left(1 - e^{-\left[\frac{T}{\alpha}\right]^{\beta}} \right) \right]$$

The system availability is:

$$Av(T)=1-\frac{\left[MTTR_p\left(e^{-\left[\frac{T}{\alpha}\right]^\beta}\right)+MTTR_f\left(1-e^{-\left[\frac{T}{\alpha}\right]^\beta}\right)\right]}{\int_0^T e^{-\left[\frac{t}{\alpha}\right]^\beta}dt+MTTR_f\left(1-e^{-\left[\frac{T}{\alpha}\right]^\beta}\right)+MTTR_p\left(e^{-\left[\frac{T}{\alpha}\right]^\beta}\right)}$$

The total revenue obtained by the outsourcer is:

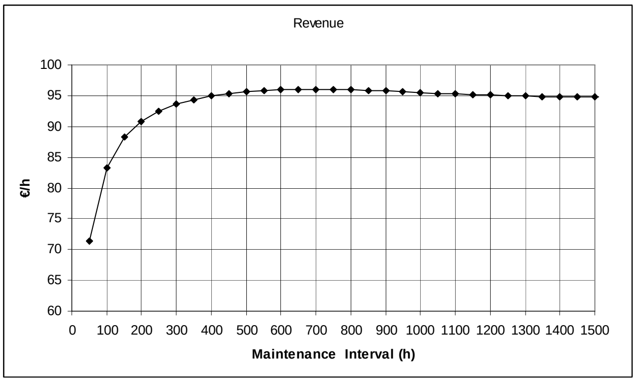


Figure 3: *Outsourcer's total revenue per unit time*

The T* that achieves maximum availability is approx. 700 h with a maximum revenue of 95,99 €/h. With a fixed fee contract with W=50 €/h the profit functions obtained are given in figure 4:

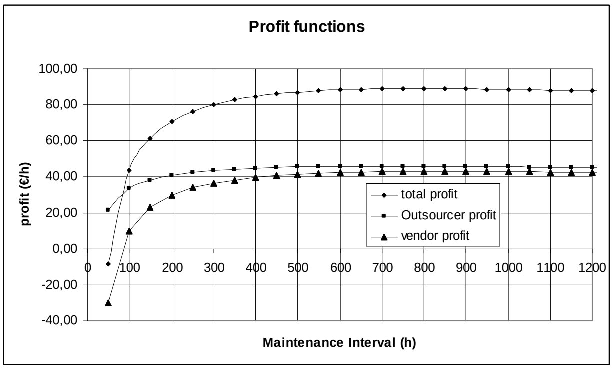


Figura 4: *Profit Functions*

The un-coordinated solution scheme is given in the following table 1, where solution 1 corresponds to maximum outsourcer's profit, solution 2 corresponds to maximum vendor profit, and solution 3 corresponds to maximum global profit. With a linear penalty function contract, by defining: a = 100 and k = 50, and σ* = 0,9591 the outsourcer's profit becomes constant, and consequently the total profit is an affine function of the vendor profit. The maintenance interval that achieves maximum vendor's profit will consequently ensure the achievement of total system profit also. The k parameter on the other hand will define the revenue sharing level. The coordinated solution given in table 2:

	T*	Av	Total	Vendor	Outsourcer
1	700	0,9599	88,78	45,99	42,79
2	800	0,9591	88,90	45,83	43,01
3	850	0,9583	88,89	45,96	42,92

Table 1: *Optimal profits per hour (€/h)- un-coordinated sol.*

T*	Av	Total (€/h)	Vendor (€/h)	Outsourcer (€/h)
800	0,9591	88,90	42,91	45,99

Table 2: *Optimal profits per hour – coordinated sol*

CONCLUSIONS

In the present paper the opportunities of coordination in a GS maintenance contract have been investigated. The methodology proposed is based on the calculation of the total expected maintenance cost and total expected revenue. The maintenance cost is incurred by the vendor, while the revenue is obtained by the outsourcer. The model consists in the calculation and comparison of the individual (decentralized) and the global (centralized) profit functions. The proposed model proves that coordination among the vendor and the outsourcer is possible in maintenance global service contracts provided that penalties and/or incentives related to a performance measure are consdiered. In the numerical application proposed the performance measure adopted is the system availability. The obtained results prove that establishment of proper contract parameters such as a linear penalty rate, fixed fee and performance penalty threshold allows the achievement of system coordination.

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