PONTIFICIA UNIVERSIDAD CATOLICA DE CHILE
SCHOOL OF ENGINEERING

EFFECTS OF TECHNOLOGY INVESTMENT IN PERFORMANCE BASED MAINTENANCE CONTRACTS

RODRIGO SEBASTIÁN ULLOA CORREA

Thesis submitted to the Office of Research and Graduate Studies
in partial fulfillment of the requirements for the degree of
Master of Science in Engineering

Advisor:
ALEJANDRO MAC CAWLEY VERGARA

Santiago de Chile, October 2016

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ABSTRACT

Equipment availability in asset intensive industries, such as mining, has a number of related decisions that need to be addressed. Determining a good maintenance policy for the equipments is one of them. Companies must decide to perform the preventive maintenances by themselves or to outsource this function to an external supplier.

If the maintenance function is given to an external provider, he will be required to perform an initial technology investment in order to offer the required service level while reducing operational costs. If the vendor incurs in such investment, he may realize more benefits from the future cash flows related to the contract. In this thesis we will look at this case, where the equipment maintenance is outsourced to an external company, which has the option to invest in technology at the beginning of the contract. For a required contract length and number of preventive maintenance interventions, the research questions are: How much should the vendor invest in technology and how much should he charge for each intervention? Do the client/vendor agree on the optimal investment level? Is there an optimal contract coordination mechanism for the agents?

The contribution of this work is to analyse and determine the effect of the initial investment level on the contract terms, by developing a mathematical model that evaluates the expected Net Present Value (NPV) from the contract for each party of the Supply Chain (SC). The model determines the optimal contract terms for each one. Also, the optimal contract for the chain is presented by considering both party members as unique entity.

Results indicate the optimal contract terms are different if they are considered as a chain rather than separately. Also, there is a contract structure (contract length, number of PM, price, and investment amount) that maximizes the benefit obtained by each party member and a coordination mechanism that is able to maximize the NPV for the entire SC.

Keywords: Outsourcing, Preventive Maintenance, Technology Investment, Net Present Value Analysis, Chain Coordination.

RESUMEN

En industrias intensivas en capital, como la minería, la política de mantenimiento de los equipos es muy relevante. Una de las principales decisiones a tomar es si el mantenimiento del equipo será realizado de forma interna o externalizado a una empresa especialista.

El proveedor del servicio de mantenimiento puede realizar una inversión inicial en tecnología para ofrecer un mejor nivel de servicio o reducir sus costos operacionales. Si el proveedor invierte en tecnología obtendrá mayores beneficios de los flujos futuros asociados al contrato. En este trabajo se analiza el caso en que la mantención de los equipos es externalizada a una compañía que tiene la opción de invertir en tecnología al comienzo del contrato. Para una longitud de contrato y cantidad de intervenciones, surgen varias preguntas: ¿Cuánto se debe invertir en tecnología y cuánto se debe cobrar por cada intervención? ¿Tienen el cliente y proveedor el mismo nivel de inversión óptimo? ¿Existe un mecanismo de coordinación óptimo para ambas partes?

La contribución de este trabajo es un análisis del efecto de la inversión inicial en los términos del contrato. Se presenta un modelo que evalúa el Valor Presente Neto (VPN) del contrato para cada parte de la cadena. Con este modelo se pueden encontrar los términos óptimos del contrato para cada uno. Además, se presenta el contrato óptimo para la cadena considerando a ambas partes como una sola entidad.

Los resultados muestran que los términos del contrato óptimos son diferentes si se consideran como una cadena o por separado. Además, existe una estructura de contrato (duración, número de MP, precio y nivel de inversión) que maximiza el beneficio obtenido por cada parte involucrada, y un mecanismo de coordinación que maximzia el VPN para la cadena completa.

Palabras Claves: Externalización, Mantención Preventiva, Inversión en Tecnología, Análisis de Valor Presente Neto, Coordinación de cadena

1. INTRODUCTION

1.1. Background

1.1.1. Mining Industry Background

The mining industry is one of the main economic sectors of the Chilean economy. In 2015 it accounted for 9% of the Chilean Gross Domestic Product (GDP) (Banco Central de Chile, 2016). The mining industry has been exporting more than US$ 43.000 millions annually over the last five years. In 2015 it corresponds to the 53.2% of the national exports. The relevance of this sector is clear since it contributes to the total employment providing more than 9.5% of the jobs over the last six years (Consejo Minero, 2016).

The main extracted and exported mineral is copper, which in 2015 corresponded to 92% of the national mining exports and a 30% of the global copper production (Consejo Minero, 2016). As any other commodity, copper prices variations depend on the global market trends. Since 2011, the price of this mineral has decreased from US$ 4 per pound to US$ 2.14 per pound (InfoMine, 2016). This situation has forced the industry to incur in efforts of optimizing and generating efficiencies in the extraction and transport processes, in order to reduce operational costs so they can keep being competitive.

The mining activity consists in extracting raw materials from either open pit and/or underground mining. To perform this activity, a mineral deposit has to be found and the mineral resources need to be pre-evaluated, in order to develop an extraction project that considers the mine construction and operation over the time required to extract the minerals. Once the project and all the construction and operating licences are approved, the company will start to construct the infrastructure needed and acquire the equipment and machinery required for the specific conditions of the mine. The first step in the mining process is the extraction where drills are required to dig through the soil; bulldozers, to remove the material and put it on trucks; and the trucks themselves, to transport the material. After that in the processing facility, mills, refineries and furnaces are used to process and transform the extracted material to a refined an transportable form.

This work will focus on the operation needed for the transport of the materials and minerals, which composes a significant part of the mining operative costs. For open-pit mines in Chile, these transport costs range between the 50% and 60% of the operating costs (Comisión Chilena del Cobre, 2015). As the equipment functions are very specialized and the extracted volumes are very high, the required equipment is expensive. In 2015 the mining industry in Chile produced 5.76 millions of metric tons of refined copper (Consejo Minero, 2016). The price of each mining truck may vary between US$1 million to US$4 million, depending on the truck capacity (Comisión Chilena del Cobre, 2015).

Because of the amount of equipment involvement in the production process, the mining sector is highly dependent on the equipment productivity and its availability. So, determining an adequate maintenance policy for the equipments is a crucial decision for the productive process. In determining such policy, companies must first decide to perform the preventive maintenances by themselves or to outsource this function to an external supplier.

Also, due to the high equipment dependency and costs, there are some aspects that must be considered around this topic. First, the company can own or lease the equipment to a third party. This strategic decision depends on the company strategy and business model. If the company decides to own the equipment, a significant initial investment level is required in order to purchase the equipment and also a constant flow is needed to keep them fully functional. Transport trucks can reach up to a 30% of the whole project investment (Comisión Chilena del Cobre, 2015). On the other hand, if a company decides not to own the equipment, the initial investment level will be significantly reduced, but operational costs will be increased since a leasing cost that must be paid during a determined period to the equipment or service provider. As these activities can last for significant periods of time the equipment, the ownership/externalization decision must be taken with special care due the high cost associated.

For both cases there are some additional aspects that must be considered. The first one is equipment selection, since there are many alternatives to transport the mineral through the entire process, companies must decide which one is the best that satisfies their needs.

The second, is the optimal availability level of the equipment in order to reduce operating costs due to logistic and operational inefficiencies.

Finally, mining companies needs to consider that in order to keep the equipment operational, a maintenance or replacement policy must be determined. They can either adopt a policy to perform a regular preventive maintenance of the equipment; a reactive maintenance, after a fail occurs, or it can choose to replace the equipment after a defined time of use. In the case of performing a regular maintenance of the equipment, an additional decision is if the maintenance will be performed by the company by its own, or if it will be outsourced to an external company specialised in maintenance services.

This research focuses on the case where a company decides to outsource its equipment maintenance. In order to outsource this function the owner of the equipment, the mining company or client, must stablish a contractual agreement with a maintenance providing company, the provider. In this agreement the client must specify the length of the contract and number of preventive maintenance interventions; and with this information the service provider will determine the price and the investment level required to meet the client's requirements. The main contribution of this work is to analyse the effect of the initial investment level over the desired contract terms and the optimal contract configuration for both parties.

1.1.2. Maintenance Outsourcing

Outsourcing is the process by which companies contract or subcontract some of its non-core activities to free up cash, personnel, time, and facilities for activities in which a company holds competitive advantage. By outsourcing some business aspects, companies can concentrate on what they do best and thus reduce costs (WebFinance Inc, 2015).

By outsourcing some non-crucial task to an external entity, companies can focus their efforts and resources to their own core-business activities in a more efficient way. On the other hand, due a growing trend of outsourcing some activities there are companies which core business is provide this required service and perform the outsourced activity. As the service provider is specialized on the outsourced activity, he can offer a better reliability and higher service level to the client. Also, the vendor can generate efficiencies to achieve lower costs.

In the mining industry one of the most commonly outsourced function is the equipment maintenance. By doing so the mining company stop worrying about this function while a maintenance service provider guarantees a required service level and uptime of the machinery, offering an specialized service at lower costs. This provides the mining company the opportunity to focus its productive resources on its own core-business activity and operation.

Outsourcing is only possible if the client is assured that the service will be provided by the vendor as required and the equipment will be operative as planned. To assure that the desired parameters are met by the provider, a contract agreement between the vendor and the client is the preferred structure in order to guarantee compliance.

The service contract objective is to define and guarantee that the service delivery procedures and quality are duly met. This legal document must consider operative, legal and financial aspects and compromises for each party involved. All definitions and involved members requirements will be traduced on the contract terms. These terms guarantees a clear understanding for both party members of what to expect from each other, and which obligations have each one against the other.

In the contract negotiation process each party member tries to define the contract terms as the ones which maximize its own benefit, even if by doing this the counterpart will get losses from the contract. In order to achieve an agreement between both parties, they must concede in some contract terms and require others until both the client and the vendor agrees a contract configuration which satisfy both party interests and needs.

1.1.3. Maintenance Service Contract

A maintenance service contract is a legal document containing the definitions, responsibilities and compromises for each party involved in the contract of a maintenance outsourcing case. In the case of service providing contracts, it must contain a detailed specification about the service which will be provided and how it will be delivered, indicating: the length of the contract, the payment structure and any other specification required to reach an agreement between the parties. The main function of a contract is to provide assurance to the parties that everything related to the service, its deliverance and payment will be delivered according to what both parties agreed upon.

A maintenance service contract must specify the following two aspects for both parties: duration, which specifies for how long the contract will be active, and the payment structure, to define when and how the client will pay the provider for the delivered services. In particular a maintenance service contract considers preventive maintenance interventions (PM) to avoid equipment failures and keep it functional, and reactive maintenance interventions in case an unexpected failure occurs.

The following terms must be defined in a regular maintenance service contract:

• Required service level. The required level of uptime for the equipment that the provider must guarantee. This uptime level can be translated directly into a number of PM.

• Time interval between PM interventions. The time between two consecutive PM, which affects the service level and equipment uptime. This value is generally constant and relates to the number of PM that will be delivered.

• Price of PM. The price paid by the client for each intervention. This value must be agreed before the contract starts.

• Unexpected failure responsibility. During the contract length the equipment can unexpectedly fail and the provider must fix the equipment and perform a reactive repair. The extent to which the provider is responsible for fixing the equipment must be agreed between the parties.

The specific mechanism by which the contract is defined can vary, but in general the most common structure is: First, the client defines a contract length and a number of preventive maintenance interventions and will request a price quote from a number of vendors. The vendor will analyse the client requirements in order to provide a price for the interventions in the contract, determining the optimal level of investment required to provide the interventions. The client will have a limited budget so the vendor will offer him a contract with an accordingly duration and number of PM.

1.1.4. Investment in Maintenance

Every maintenance operation needs an specific level of assets and equipment that are required to perform the maintenance operations. Innovation in technology or investment on other non essential assets can improve the maintenance process or reduce the operational cost. Investing in innovative technologies has a risk, but can provide efficiencies in the process that will reflect in costs reduction and improved reliability from the maintenance process. Another type of investment is the one related to the training of the employees which can also be seen as a capital investment.

There is a trade-off between the level of initial investment and potential benefits in operational costs. For example, if the vendor performs an over-investment while the benefits in operational cost are lower than expected, the value of the contract for the provider can be zero or negative. On the other side, if the vendor performs an optimal level of investment and the operational benefits are higher than expected, the value of the contract for the provider will be increased. It is important to notice, that in presence of some uncertainty or risk not all companies will be interested in a determined investment, since the required investment may not be compensated by the risk on the future benefits.

By investing in technology, maintenance companies can provide lower operative costs, higher process capacity, higher processing speeds, better reliability, reduced process variations, etc. As different industries may have specific needs and resources, the required technology investment options and levels may vary. For example, in the case of the wind power industry, the providers have invested in technology in condition monitoring system to predict the need of maintenance which has significantly reduced the PM intervention cost (Nilsson & Bertling, 2007).

It is common practice that investment decisions are made during the negotiation process or previous to closing contract closure. In this way, the provider costs, efficiency and desirable contract length and times can be adjusted against the level of agreed investment. Also, if the vendor is able to generate benefits from the investment, he can transfer part of them to the client; in the form of: expected service level, higher reliability, or even a contract price reduction.

1.1.5. Service Contract Coordination

Each party involved in a contract, will have different interests and will try to maximize is own profit from the contract, even if by doing so, it can negatively affect their counterpart. As part of the contract negotiation process, both party members will request and concede on some terms until they both reach an agreement on how the contract will be defined. This situation commonly produces a contract which consider a suboptimal configuration for both parties as a chain (Whang, 1995). In order to solve this issue a coordination mechanism must be considered to align both parties incentives, in order to end with a contract which maximizes the overall benefit for both parties.

Some mechanisms considers a revenue sharing policy, where both parties shares part of the expected benefit from the contract (Cachon & Lariviere, 2005; Giannoccaro & Pontrandolfo, 2004). Others considers a cost subsidization mechanism where one member transfers part of the benefit to his counterpart for accepting a contract which increases his costs (Tarakci, Tang, Moskowitz, & Plante, 2006a). Similar is the case when the producer wants to control the demand and offers a quantity discount to the retailer (Dolan, 1987; Goyal & Gupta, 1989).

In case of performing a technology investment, the future cash flows related to the contract will be affected and by doing so the expected benefits from the contract will vary too. This situation will produce a negotiation process between the involved members. A coordination mechanism may be needed to achieve the optimal contract terms in presence of an initial investment.

1.2. Objectives

The main objective of this research is to study and analyse the effects of technology investment in performance based maintenance contracts. In order to achieve this main objective we have defined three secondary objectives:

(i) Develop a performance based maintenance contracts mathematical model. The model links the preventive maintenance interventions and the initial investment level, in order to determine if there exist a trade-off between these two parameters which needs to be considered at the moment of defining the contract terms.

(ii) Determine the optimal investment level which maximizes the profit of each party member and analyse if the initial investment has an effect over the profit of each party member.

(iii) Study the existence of a global optimal which maximizes both parties profit as a complete chain and determine if this optimal can be reached with some coordination mechanism.

1.3. Hypothesis

In order to achieve the proposed objectives we propose the following research hypothesis:

(i) The initial investment level has a direct effect over the expected profit from the contract for each party member.

(ii) There exists an optimal investment amount that maximizes the profit for each party member.

(iii) A global optimal that maximizes the profit of both party members can be achieved through a coordination mechanism.

1.4. Thesis Outline

This thesis is based on the presentation of a paper that shows the main findings of the research. The thesis is organized as follows. Chapter 1 is an introductory section that presents the context and the main objectives of this work. Chapter 2 corresponds to the journal article written from this work. Finally, Chapter 3 contains the main conclusions of this work and suggests some further research around this topic.

2. TECHNOLOGY INVESMENT EFFECTS IN PERFORMANCE BASED MAINTENANCE CONTRACTS

This work analyses the effects of a fixed entry investment cost, in technology or infrastructure, on performance based maintenance contracts. We present a mathematical expression which reflects the trade-off between an early technology investment, performed by the vendor, and the cost of its future interventions. We develop a mathematical model of a performance based maintenance contract which incorporates this technology trade-off expression and models the value of the contract for the client and the service vendor. The client defines the duration of the contract and the number of the maintenance interventions, in order to achieve an optimal availability level, and then the vendor quotes the cost of the interventions. We study how the amount of initial technological or new equipment investment and the contract parameters affect the net present value for each party and the entire supply chain. Demonstrate the existence of an optimal relation between the number of preventive maintenance interventions and level of initial investment for the vendor. Analytically derive the optimal contract parameters for the client, vendor and entire supply chain and show that they differ from each other, indicating a lack of coordination for the entire chain. To achieve coordination, we present a revenue sharing mechanism which maximizes the net present value of the entire chain. Finally, using information from the mining sector, we present an application to a case study and results.

2.1. Introduction

Currents trends show that there is a growing tendency to outsource some non-business core tasks. Yang, Kim, Nam, and Min (2007) indicates that the degree of asset specificity has an important influence on the outsourcing decision. This is especially common for asset intensive industries like mining where uptime is critical, so they can focus their efforts on achieving a better performance. Cruz, Haugan, and Rincon (2014) empirically shows that the maintenance financial performance is influenced by the assets specificity. This asset specificity creates an scenario in which firms face the decision to accept higher transaction costs and provide quality service, or shirk these costs by providing lower quality service.

Moreover, the vendor can offer lower costs and increase reliability. Although it has been proven that outsourcing non-strategic functions helps both parties to focus on their core business (Kersten, Hohrath, & Böger, 2007). A common situation in outsoursing contracts is the one in which each party looks towards maximizing its own expected profit without looking at the potenital benefits of the whole service supply chain (Wong & Jaya, 2008). In response to this behaviour, generally a number of constrains are introduced in the contract in order to induce mutual cooperation.

Depending on level of outsourcing and importance of maintenance operations, contracts can present different designs and structures (Govindan, Popiuc, & Diabat, 2013; W. Wang, 2010), and they can describe different control mechanisms, operation procedures and transaction characteristics (Greenberg, Greenberg, & Antonucci, 2008). In particular, a performance based contract can be seen as an extension of a traditional building contract, that has a defined length, determined costs and service level (Lambropoulos, 2007). A performance based contract focuses on developing strategic performance metrics and directly relates the contract payment to performance against these metrics (Hensher & Houghton, 2004). Common performance metrics are availability, reliability and maintainability, among others.

Contracts and technology adoption has been previously studied in the context of economic and management literature, mostly focusing in the investment in information technologies (Acemoglu, Antras, & Helpman, 2007; Bakos & Brynjolfsson, 1993a, 1993b; Wathne & Heide, 2000). Tseng, Tang, Moskowitz, and Plante (2009) models the adoption in time of new technology adoption in maintenance outsourcing contracts from the manufacturer perspective. Reductions in the cost of future preventive maintenance interventions have been extensively studied in the context of learning and forgetting effects (Tarakci, 2016; Tarakci, Tang, & Teyarachakul, 2009, 2013). To the authors knowledge, this is the first paper that studies the optimal amount of technology investment and its effects in performance based maintenance contracts from a reliability and supply chain perspective. Specially with an application to an specific asset intensive industry.

Our contribution is twofold: first, the development of a mathematical model of a performance based service contract model between a client and the a vendor which reflects the trade-off between an early technology investment, performed by the vendor, and the cost of its future interventions. Second, analytically show the existence of an optimal relation between the number of preventive maintenance interventions and level of initial investment for the vendor, obtaining the optimal contract parameters for the client, vendor and entire supply chain. Along with a coordination mechanism. To the authors' knowledge there are no previous studies of the effects of an initial investment in the value of a performance based maintenance contract for each party, the entire chain and on how it affects the contract terms and the decision making process. To illustrate the value of the proposed model, we present an application in a case study in the mining sector.

The paper is structured as follows. Section 2.2 presents a literature review of previous contract models and how technology affects maintenance costs. Section 2.3 describes the methodology and the analysis of the initial investment. Section 2.4 and 2.5 presents the case study parameters and the results of different scenarios. Finally, section 2.6 shows the main insights and conclusions.

2.2. Literature Review

The main approaches used to model service contracts and the interaction between a client and a service provider are principal-agent models (Baker, 1992; Gupta, Vedantam, & Azadivar, 2011; Y. Wang, Wallace, Shen, & Choi, 2015), game theory (D. Murthy & Yeung, 1995; Steinacker, 2004), incentive mechanisms (Tarakci et al., 2006a; Tarakci, Tang, Moskowitz, & Plante, 2006b) contract pricing (D. Murthy & Yeung, 1995) and contract negotiation (Jackson & Pascual, 2008). Typical applications of service contracts can be found in manufacturing (Ding, Lisnianski, Frenkel, & Khvatskin, 2009; Jackson & Pascual, 2008; Kumar, Markeset, & Kumar, 2004; Martin, 1997; D. Murthy & Asgharizadeh, 1999; Tarakci et al., 2006a), aviation (Bowman & Schmee, 2001; Hong, Wernz, & Stillinger, 2015), healthcare (Ellwood et al., 1971) and medical devices (Cruz & Rincon, 2012).

Principal-agent models analyse the decisions, interactions and objectives of a principal who seeks services from the agent in return for a payment (Hong et al., 2015). In the proposed contract structure, the customer plays the role of the principal and seeks for a desired level of equipment availability, based on a number of preventive and corrective maintenance that the agent has to perform. As part of the contract, the principal also demands advanced technological systems, in order to reduce future maintenance costs. To fulfill these requirements, the agent needs an initial investment in technology, which allows him to set a determined price for each maintenance.

No previous studies have focus on the effects of technology investment on performance based contracts. Nonetheless, there is some literature related to technology in contractual relations. Aghion and Bolton (1992) analyse long-term financial contracts between an entrepreneur and a wealthy investor and how the project must be controlled under different circumstances. Massell (1962) relates the rate of investment on a business with the adoption of new technology and studies the impact of this investment on the output per man-hour. Acemoglu et al. (2007) present a contract where the technology investment is choosen by the client for contractible activities and by the supplier for noncontractible activities. Tseng et al. (2009) model a flexible maintenance contract, which captures any technological changes during the contractual period. The same principle is considered in the author's model, with an infrastructure or technology investment at the start of the period that will be reflected in future reductions in service costs. Examples of companies that have enhanced their profitability by improving their maintenance can be found in the paper mill industry (Al-Najjar & Alsyouf, 2004), wind turbines (Basim, 2012) or the car industry (AlNajjar & Jacobsson, 2013).

The necessity to model contractual relations has become evident in recent years. In their review, D. N. P. Murthy, Jack, and Kumar (2013) emphasize the need for a quantitative approach to evaluate different contracts, taking into account the interests of the different parties involved. They indicate that in the definition of the contract there are technical and economic issues that require attention, such as incentives and/or penalties for availabilities, price, and fees. Pascual, Santelices, Liao, and Maturana (2016) present a model to determine the optimal number of preventive maintenances for a fixed term contract using the Net Present Value analysis for the vendor, the client and for both parties as a chain. In the model, the client requires a certain contract length and number of preventive maintenance interventions, and the vendor proposes a price for that contract.

This paper focuses on a finite horizon maintenance problem and the proposed contract strucuture is based on an agreed availability required by the client for the equipment, inspired on the previous work by Pascual et al. (2016). In service maintenance contracts, generally the client defines the duration and number of preventive interventions as a single decision maker (Tayur, Ganeshan, & Magazine, 2012). While the vendor uses this information to determine the price of the contract in order to meet the desired maintenance requirements and make the contract profitable for him. Also at the same time he must determine the optimal initial level of investment in technology, which will affect the intervention costs and will improve the provided service (Jackson & Pascual, 2008).

2.3. Methodology

The performance based maintenance contract considers a single period maintenance service contract with a fixed length T_m and $n+1$ preventive maintenance (PM) interventions. The duration of each PM is represented by T_p and the time interval between two consecutive PM is denoted by T. The technology investment effect is represented by a monotonic decreasing function to the level of investment I_c at the beginning of the contract, which represents the future cost of each PM intervention C_{ip}. The relation between T_m, T_p and T can be expressed as:

$$T_m = (n+1)(T+T_p), n \in \mathbb{Z}^+ \tag{2.1}$$

The contract setting is as follows: the client first defines the duration and number of preventive maintenance interventions as a single decision maker and with this information the vendor determines the price of the preventive maintenance interventions and the level of initial investment.

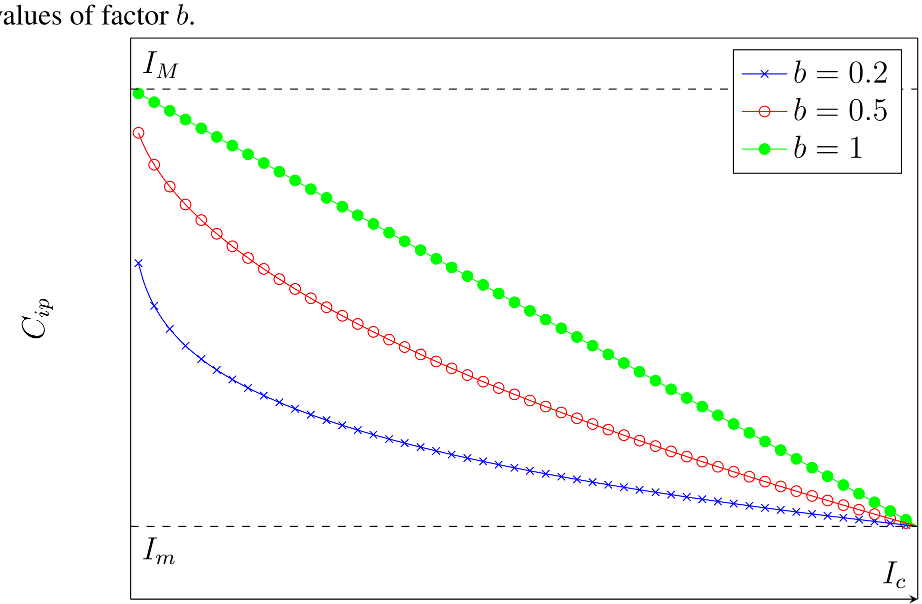
We consider an initial investment amount of I_c at the beginning of the contract. This investment affects the cost of each future PM intervention. However, as Haldi and Whitcomb (1967) suggests that the relationship between the initial investment and the final output is not proportional. So we propose the following generalized exponential function which represents a geometric relationship between the investment and each PM intervention cost.

$$C_{ip}(I_c) = (1 - a * I_c^b)R + m_c \tag{2.2}$$

Where C_{ip} represents the intervention costs, I_c the investment level, R de maximum cost reduction that can be achieved by investing in technology, m_c is the minimum PM intervention cost and b is return over technology investment coefficient. A value of $b < 1$ implies decreasing returns over technology investment, $b = 1$ shows constant returns, and $b > 1$ represents increasing returns.

Adjusting the value of b we can obtain different forms for the relation between the initial investment and the cost reduction. Figure 2.1 shows graphically this relation for different values of b.

FIGURE 2.1. Relation between the initial investment and the PM cost for different values of factor b.



From the vendor perspective, there are four main cash flows. The first one is the initial investment (I_c) that he pays at the beginning of the contract. The second is the income when the client pays for each PM. This depends on the price of each maintenance per time unit, represented by p. The third is the cost of each intervention denoted by C_{ip}. Finally, there is the cost associated to corrective maintenance (CM) due to unexpected failures, denoted by C_{ir}.

In order to achieve a win-win situation, the vendor may transfer the client part of the benefits from the cost reduction, denoted by ΔC_{ip}, offering a price discount (Kim, 2000). The PM discounted price consists on the original price p_M less a fraction of the benefits. If the vendor transfer a γ percent of the benefits to the client, then the discounted price can be defined as:

$$p(I_c) = p_M - \gamma \frac{\Delta C_{ip}(I_c)}{T_p} \tag{2.3}$$

For a single period contract, the expected NPV for the vendor with a continuous discount rate $\theta > 0$ can be written as follows,

$$\Pi_v = -I_c + \left(\int_0^{T+T_p} p(I_c) e^{-\theta t} dt - C_{ip}(I_c) e^{-\theta(T+T_p)} - C_{ir} \int_0^T \frac{\beta}{\eta} \left(\frac{t}{\eta}\right)^{\beta-1} e^{-\theta t} dt \right) \sum_{i=1}^{n+1} e^{-\theta(T+T_p)(i-1)} \tag{2.4}$$

Note that

$$\int_0^T t^{\beta-1} e^{-\theta t} dt = \frac{1}{\theta^\beta} \Gamma_{inc}(\beta, \theta T) \tag{2.5}$$

where Γ_{inc} represents the lower incomplete gamma function. Then, the NPV for the vendor can be represented as,

$$\Pi_v = \underbrace{-I_c}_{\text{Initial investment}} + \left(\underbrace{p(I_c)\frac{(1-e^{-\theta(T+T_p)})}{\theta}}_{\text{Income}} - \underbrace{C_{ip}(I_c)e^{-\theta(T+T_p)}}_{\text{PM Cost}} - \underbrace{\frac{C_{ir}\beta}{(\eta\theta)^{\beta}}\Gamma_{inc}\left(\beta,\theta T\right)}_{\text{Repair cost}} \right) \alpha \quad (2.6)$$

where

$$\alpha = \frac{e^{\theta(T+T_p)} - e^{-\theta n(T+T_p)}}{e^{\theta(T+T_p)} - 1} \quad (2.7)$$

where α is obtained by an algebraic manipulation of the NPV function.

On the other hand, the expected NPV for the client depends on three main cash flows. The first is the uptime revenue of the equipment, denoted by c_f. The second corresponds to the price paid for each PM intervention. Finally, the third is the lost revenue while the equipment is not available due to unexpected failures.

For a single period contract, the expected NPV for the client can be written as follows,

$$\Pi_c = \sum_{i=1}^{n+1} \left(\int_0^T c_f e^{-\theta t} dt - \int_0^T \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} c_f T_r e^{-\theta t} dt - \int_0^{T+T_p} p(I_c)e^{-\theta t} dt \right) e^{-\theta(T+T_p)(i-1)} \quad (2.8)$$

Analogously to the vendor's case, the clients profit function Π_c is:

$$\Pi_c = \left(\underbrace{c_f\frac{(1-e^{-\theta T})}{\theta}}_{\text{Revenue}} - \underbrace{p(I_c)\frac{(1-e^{-\theta(T+T_p)})}{\theta}}_{\text{PM price}} - \underbrace{\frac{c_f T_r\beta}{(\eta\theta)^{\beta}}\Gamma_{inc}\left(\beta,\theta T\right)}_{\text{Lost revenue}} \right) \alpha \quad (2.9)$$

In order to study the contractual relation as a chain, the benefits of both parties must be considered. Therefore, the chain's expected NPV is defined as the sum of both NPVs function:

$$\Pi_{chain} = \Pi_v + \Pi_c$$

The proposed model considers the following assumptions:

• A single client and a single vendor.

• Complete and perfect information on both client and vendor sides.

• PM interval decision is delegated to the vendor.

• Parameters of equipment reliability follow a power law NHPP process between PM (Duane, 1964), with an increasing failure rate. This process is commonly used to describe a failure mechanism in the maintenance and reliability literature because it can model many distribution forms by changing its parameters.

• Perfect preventive maintenance is considered. This assumption is commonly used in the maintenance and reliability literature, and the results of this work remain unchanged as long as the failure rate remains constant over time.

• Minimal repair is considered for corrective maintenance, with small repair time. This means a CM restores the process back to operation and the deterioration of the process remains during CM.

• Costs are defined at the beginning of the contract and remain constant over the contract duration.

• Full disclosure of equipment revenue by the client. This assumption may be a little impractical in some situations, but in the case of capital intensive industries, like the mining industry, this information is well known by vendors due to the high mobility of workers between companies.

2.4. Case Study

We present an application to a mining case study which uses similar parameters to those used by Pascual et al. (2016) and we add some new ones to account for the initial investment. In our proposed model the individual PM cost (C_{ip}) and the price (p) are defined as functions of the initial investment (I_c). The contract has an optimal fixed length of T_m time units (tu). Table 2.1 shows the values of the parameters used in the case study.

TABLE 2.1. Case study parameters.

Parameter	Value	Units
T_m	75	tu
T_p	0.5	tu
T_r	1.5	tu
θ	0.008	-
η	3	1/tu
β	3	-
C_{ir}	2.5	mu
c_f	8.5	mu/tu
p_M	4.5	mu/tu
γ	0.07	-
M_c	8	mu
m_c	2	mu
a	0.01	-
b	0.2	-

2.5. Results and Discussion

We will start by defining the optimal number of PM interventions for the client which maximizes his NPV, since he is the one who defines this parameter in the contract. Then we will determine the optimal number for the vendor and analyse if both parties agree on the same optimal number of PM interventions. As *Lemma* 2.1 shows, an agreement between the client and the vendor is not achievable.

Lemma 2.1. *A agreement in the number of PM interventions between the client and the vendor is not achievable.*

Proof: From Equation 2.9 we can obtain the optimal time T between PM interventions for the client,

$$\frac{\partial \Pi_c(T)}{\partial T} = \left(c_f - p(I_c)e^{-\theta T_p} - \frac{c_f T_r \beta T^{\beta-1}}{\eta^\beta} \right) \frac{e^{(-\theta T)}(e^{\frac{\theta T_m}{n+1}} - e^{\frac{-\theta n T_m}{n+1}})}{e^{\frac{\theta T_m}{n+1}} - 1} = 0 \qquad (2.10)$$

If we multiply by $e^{\theta T_p}/e^{\theta T_p}$ we obtain,

$$\frac{\partial \Pi_c(T)}{\partial T} = \left(c_f e^{\theta T_p} - p(I_c) - \frac{c_f T_r e^{\theta T_p} \beta T^{\beta-1}}{\eta^\beta} \right) \frac{e^{(-\theta T)}(e^{\frac{\theta T_m}{n+1}} - e^{\frac{-\theta n T_m}{n+1}})}{e^{\theta T_p}(e^{\frac{\theta T_m}{n+1}} - 1)} = 0 \qquad (2.11)$$

If we define,

$$g_\theta(T) = \frac{e^{\theta T_p} \beta T^{\beta-1}}{\eta^\beta} \qquad (2.12)$$

Equation 2.13 presents the expression which determines the optimal number for the client.

$$g_\theta(T_c^*) = \frac{c_f e^{\theta T_p} - p(I_c)}{c_f T_r} \qquad (2.13)$$

Analogously for the vendor case we can obtain the an expression which determines the optimal number for the vendor in Equation 2.14.

$$g_\theta(T_v^*) = \frac{\theta C_{ip}(I_c) + p(I_c)}{C_{ir}} \qquad (2.14)$$

Finally, if we take the complete supply chain NPV by taking the sum of Equations 2.13 and 2.14 to determine the optimal time between interventions which maximizes the NPV for the entire chain, holding all other parameters constant.

$$g_\theta(T^*) = \frac{\theta C_{ip}(I_c) + c_f e^{\theta(T_p)}}{c_f T_r + C_{ir}} \tag{2.15}$$

Given that $\theta > 0$, then $g_\theta(T)$ is positive and increases in T. So for the client, the second derivative of $\Pi_c(T)$ with respect to T is always negative, hence T_c^* must be the global solution. The analysis for the vendor and chain is the same, which implies that T_v^* and T^* are the global optimal solutions for each one respectively. $\square$

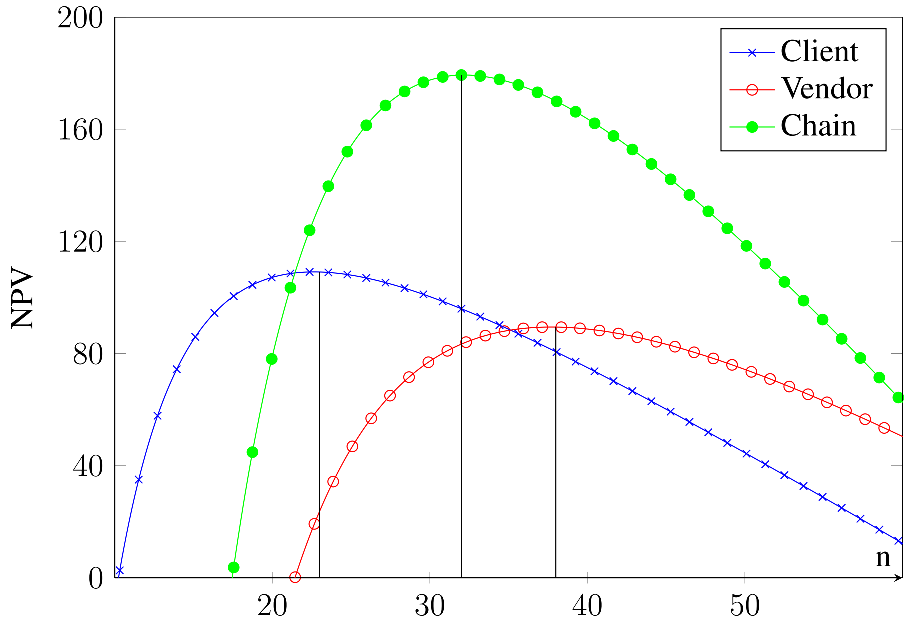
The previous result is shown in Figure 2.2 which graphically shows the relation between the number of PM interventions and the net present value (NPV) for the vendor, client and entire chain. We can observe that the number of PM interventions which maximizes the NPV for the vendor, the client and the entire chain is not unique. Since the client defines the number of interventions which will be executed, he will require his optimal level of $n = 38$, resulting in an NPV for him of 61.8. Once the client has defined the number of interventions for the contract, the provider can define the level of investment which maximize his own benefit considering the given number of PM. At the required level of PM there is an specific investment level which maximizes the benefit for the vendor and chain. The effect of the investment level for each party is show in Figure 2.3.

If we take the client NPV function (Equation 2.9) and derive it by I_c to obtain the optimal investment level which maximizes its NPV, holding all other parameters as constant, we can obtain the following expression:

$$\frac{\partial \Pi_m(I_c)}{\partial I_c} = \frac{\alpha I_c^b b R(1 - e^{-\theta(T+T_p)})(e^{\theta(T+T_p)} - e^{-\theta n(T+T_p)})}{I_c T_p \theta(e^{\theta(T+T_p)} - 1)} = 0 \tag{2.16}$$

This results show that there is no optimal investment level for the client perspective, he will always prefer the higher investment as possible. This is due due to the investment and benefit sharing sharing mechanism and the structure of the cost reduction function,

FIGURE 2.2. Optimal number of PM for each party given a contract length.



which leads to the marginal NPV benefits to be always positive to initial investment level increments. This allows the client to accept the maximum possible level of investment that the vendor is willing to perform. The proof of this is analytically shown in *Lemma* 2.2. These results are also shown in Figure 2.4.

Lemma 2.2. *For any given optimal number of PM interventions, the client will always prefer the highest possible investment level I_c performed by the vendor.*

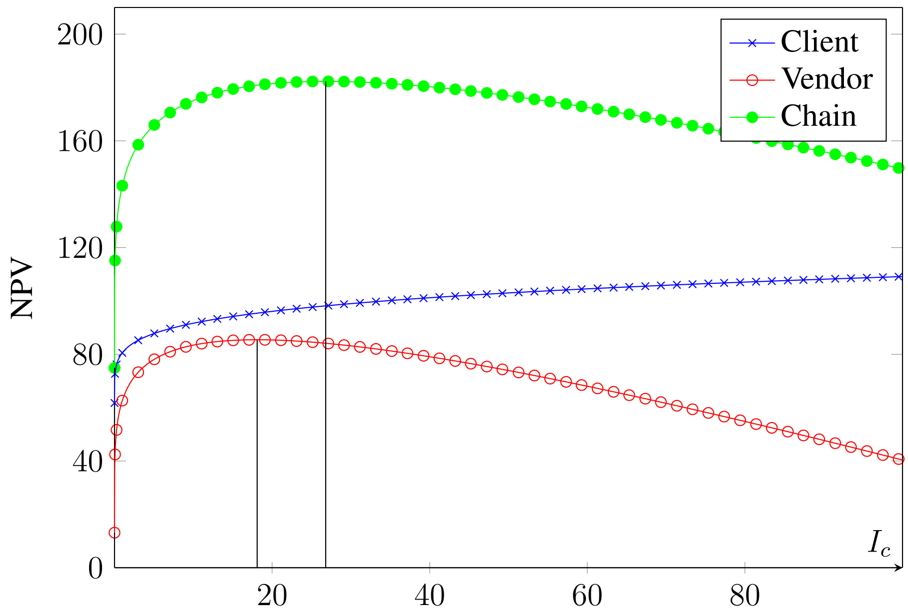
Proof: Reordering the terms in Equation 2.16 we obtain that,

$$\frac{\partial \Pi_c(I_c)}{\partial I_c} = \left(\frac{I_c^b}{I_c}\right) \frac{\alpha b R(1 - e^{-\theta(T+T_p)})(e^{\theta(T+T_p)} - e^{-\theta T_m})}{T_p \theta (e^{\theta(T+T_p)} - 1)} = 0 \tag{2.17}$$

Since $b < 1$, the marginal return on technology investment is decreasing. If we analyse the case of $I_c \to \infty$ we obtain that

$$\lim_{I_c \to \infty} \frac{I_c^b}{I_c} = 0 \tag{2.18}$$

FIGURE 2.3. Initial Investment Effect over a fixed number of PM defined by the client ($n = 38$).



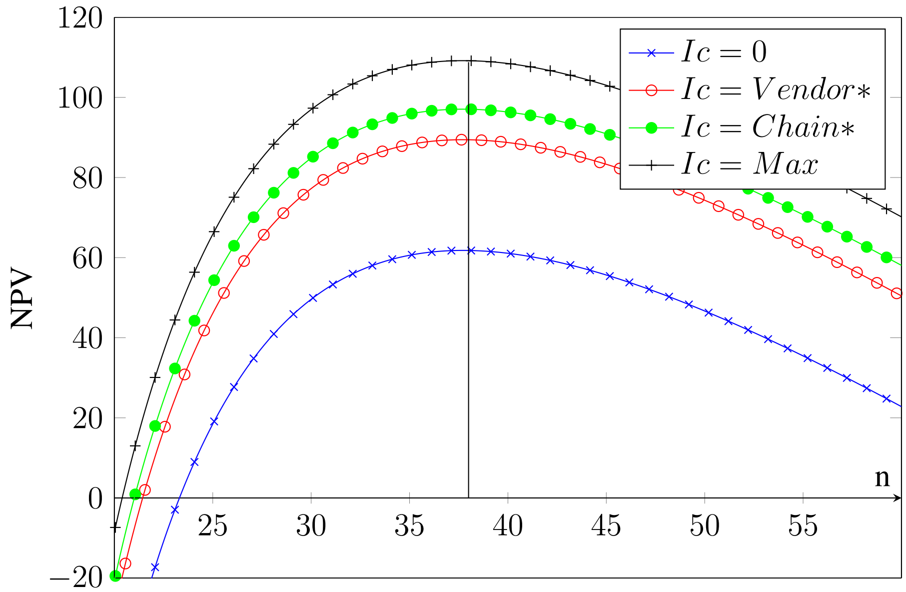
This result shows that the optimal investment level which maximizes the expected NPV for the client will be theoretically infinity, *but as this value can't be reached he will always be preferring the highest investment as possible.* □

Analogously to the client's case, if we consider the NPV function for the vendor and maximize its value against the investment level, holding all other parameters as constant, we obtain the initial investment level which maximizes the NPV for the vendor. The optimal investment level must satisfy the following equation:

$$\frac{\partial \Pi_v(I_c)}{\partial I_c} = -1 + \frac{\left(-\frac{\gamma I_c^b bR(1-e^{-\theta(T+T_p)})}{I_c T_p \theta} + \frac{I_c^b bRe^{-\theta(T+T_p)}}{I_c}\right)(e^{\theta(T+T_p)} - e^{-\theta n(T+T_p)})}{e^{\theta(T+T_p)} - 1} = 0 \tag{2.19}$$

$$I_c{}^{b-1} bR = \theta T_p \left(\frac{e^{\theta(T+T_p)} - 1}{(T_p \theta e^{-\theta(T+T_p)} - \gamma(1 - e^{-\theta(T+T_p)}))(e^{\theta(T+T_p)} - e^{-\theta n(T+T_p)})} \right) \tag{2.20}$$

FIGURE 2.4. Initial Investment Effect over the desired number of PM for the client.



The returns over technology investment (RTI) obtained by the vendor from investing in technology can be expressed as the NPV of all the future cost reduction for a given level of investment.

$$RTI(I_c) = \sum_{i=1}^{\frac{T_m}{T+T_p}} \Delta C_{ip} \frac{1}{e^{i\theta}} \tag{2.21}$$

We can obtain the marginal return over technology investment ($MRTI$) by deriving Equation 2.21 by I_c.

$$\frac{\partial RTI(I_c)}{\partial I_c} = MRTI(I_c) = {I_c}^{b-1} bR \frac{(1-\gamma)(e^{-\frac{T_m}{T+T_p}\theta} - e^{\theta})}{e^{\theta} - 1} \tag{2.22}$$

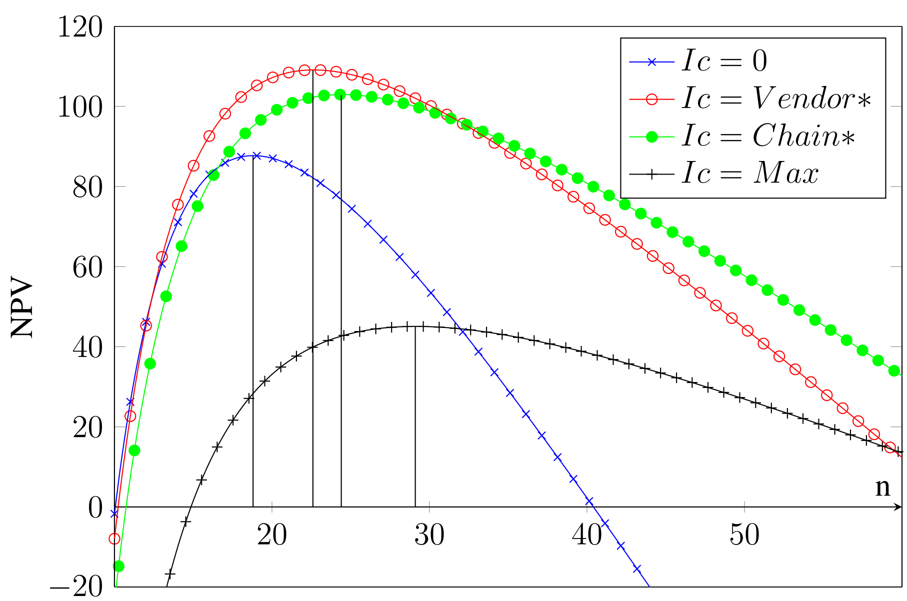
Using Equations 2.20 and 2.22, and performing some algebra we obtain:

$$MRTI(I_c) = \theta T_p \underbrace{\left(\frac{e^{\theta(T+T_p)} - 1}{(T_p \theta e^{-\theta(T+T_p)} - \gamma(1 - e^{-\theta(T+T_p)}))(e^{\theta(T+T_p)} - e^{-\theta n(T+T_p)})} \frac{(1-\gamma)(e^{-\frac{T_m}{T+T_p}\theta} - e^{\theta})}{e^{\theta} - 1} \right)}_{G(T,T_p,T_m,\gamma,\theta)} \tag{2.23}$$

$$MRTI(I_c) = G(T, T_p, T_m, \gamma, \theta) \tag{2.24}$$

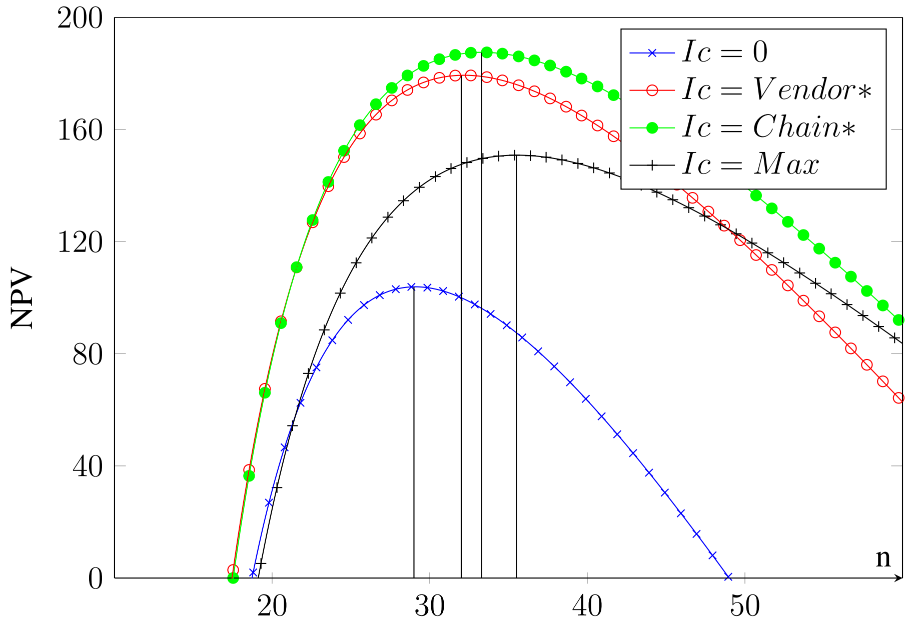
Equations 2.20 and 2.24 demonstrates the existence of a unique optimal level of initial investment which maximize the vendor's NPV for a given number of PM. Also, as the initial investment is increased, so does the number of optimal number of optimal PM. Figure 2.5 shows this results for the vendor NPV for different number of PM interventions (n) and levels of initial investment (I_c). So the vendor's optimal investment level will depend directly on the return it produces, which is given by the cost reduction in future interventions. Hence the optimal investment level will directly depend on the return over technology investment expressed in the slope of the cost reduction function. This relation is proven in *Lemma* 2.3. The analysis and result is the same for the chain, shown in Figure 2.6

FIGURE 2.5. Initial Investment Effect over the desired number of PM for the vendor.



Lemma 2.3. *Vendor's optimal investment level depends on the return over technology investment (b).*

FIGURE 2.6. Initial Investment Effect over the desired number of PM for the chain.



Proof: The vendors utility function of investing in technology (BIT) which is equal to the sum of all discounted returns of PM cost reductions ($DRCR$) minus the initial investment. The vendor will invest in order to maximize his BIT utility function. So :

$$BIT(I_c) = -I_c + DRCR = -I_c + \sum_{i=1}^{\frac{T_m}{T+T_p}} (1-\gamma)\Delta C_{ip} \frac{1}{e^{i\theta}} \tag{2.25}$$

$$\frac{\partial BIT(I_c)}{\partial I_c} = -1 + \frac{(1-\gamma){I_c}^{b-1} bR(e^{-\frac{T_m}{T+T_p}\theta} - e^{\theta})}{e^{\theta}-1} = 0 \tag{2.26}$$

$${I_c}^{1-b} = (1-\gamma)bR\frac{(e^{-\frac{T_m}{T+T_p}\theta} - e^{\theta})}{e^{\theta}-1} \tag{2.27}$$

Without loosing generality, we can assume $z = e^{\theta}$ which is a increasing function of θ. Applying this to Equation 2.27, we can obtain that the optimal initial investment for the vendor depends on z as,

$$I_c = \left((1-\gamma)bR\frac{(z^{-n} - z)}{z-1}\right)^{\frac{1}{1-b}} \tag{2.28}$$

Also we can observe from Equation 2.28 that the optimal initial investment depends of the parameters b*,* R*,* γ *and* θ*.* $\square$

LEMMA 2.3.1. *A larger cost reduction gap (R) will induce a higher investment level.*

Proof: If we take two different reduction gaps R_1 *and* R_2*, were* $R_2 > R_1$ *and maintain all the other parameters constant. From Equations 2.20 and 2.24 we obtain that in the optimum the vendor will invest until the marginal returns are equal, hence in the optimum it will hold:*

$$I_{c1}{}^{b-1} b R_1 = I_{c2}{}^{b-1} b R_2 \tag{2.29}$$

Simplifying and reordering we obtain:

$$\left(\frac{I_{c2}}{I_{c1}}\right)^{1-b} = \frac{R_2}{R_1} \tag{2.30}$$

Since $b < 1$ *so* $1 - b < 1$*, and* $R_2 > R_1$ *hence* $\frac{R_2}{R_1} > 1$*, so in order to Equation 2.30 hold it must satisfy that* $I_{c2} > I_{c1}$*. Which implies that in presence of a higher possible cost reduction gap, the vendor will prefer to invest more than the case of an smaller cost reduction gap.* $\square$

LEMMA 2.3.2. *A higher discount rate* θ *will reduce the optimal investment level for the vendor.*

Proof: From Equation 2.28, since z *is an increasing function of* θ*. We can conclude that the initial investment is also decreasing as* θ *increases. This results shows that as the discount rate increases the optimal investment for the vendor will decrease. We can also observe these results in Figure 2.7 were as the discount rate is increased the optimal initial investment is reduced.* $\square$

LEMMA 2.3.3. *Larger returns over technology investments, or values of* (b) *close to 0, will induce less technology investment by the vendor.*

Proof: Using Equation 2.29 and if we present two different cases of returns over technology investment, were case 1 (b_1) has a larger return over technology investment that case 2 (b_2), hence $b_1 < b_2$. *Keeping all the other terms constant, we can obtain the following relation that will hold in the optimum:*

$$I_{c1}{}^{b_1-1} b_1 R = I_{c2}{}^{b_2-1} b_2 R \tag{2.31}$$

Reordering:

$$\frac{I_{c2}{}^{1-b_2}}{I_{c1}{}^{1-b_1}} = \frac{b_2}{b_1} \tag{2.32}$$

Since b_1 *and* b_2 *satisfies* $0 < b_i < 1$ *and* $b_1 < b_2$, *then* $b_1/b_2 < 1$. *Since* $1 - b_1 > 1 - b_2$, *in order for Equation 2.32 to hold we need that* $I_{c2} > I_{c1}$. *Hence larger returns over technology investments* (b) *will induce less technology investment by the vendor. As the returns toward technology investment becomes smaller and lineal* ($b = 1$)*, a higher investment will be preferred by the vendor to maximize his profit. Figure 2.7 validates these results, as* b *is closer to 1 or returns to technology investment are linear, the amount of optimal investment grows exponentially.* $\square$

2.5.1. Integrated supply chain

As shown in Equation 2.15 and Figure 2.6, when both parties are considered as an integrated chain, the optimal number of PM interventions increases as the initial investment grows, similar to the vendor's case. Since both parties benefit from the initial investment, to a certain point, the maximum NPV of the chain increases as the initial investment is incremented. From a certain level forward the NPV of the chain is reduced, due to the over-investment.

FIGURE 2.7. Optimal level of investment I_c for the vendor for different combinations of θ and b.

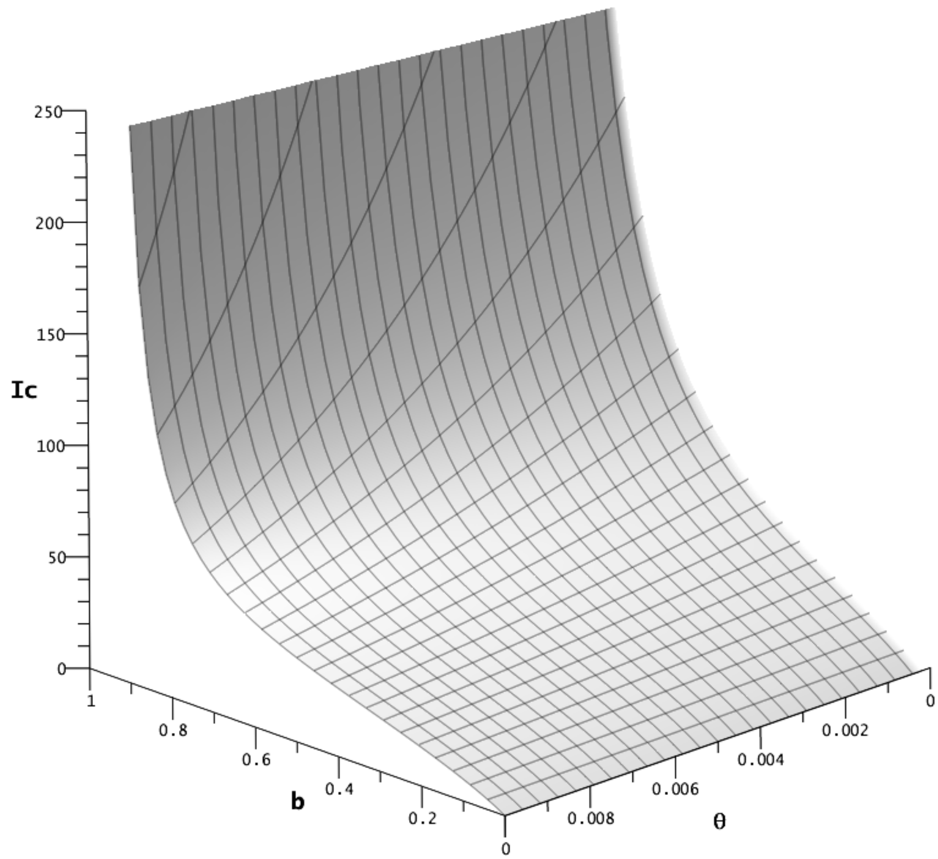


Figure 2.9 shows how the NPV changes when the vendor adjusts his initial investment level, given the optimal number of PM interventions requested by the client ($n = 38$). In order to maximize his NPV, the vendor will increase his initial investment to 18.1 which, compared to the case of no investment, have a positive impact on the vendor previous NPV, increasing by 549.7%. This will also impact the client and the chain NPV, resulting in increments of 54.5% and 141.4%, respectively. This gain in value for all agents in the supply chain, is a result of the reduction in the cost of the PM interventions due to the higher initial investment level performed by the vendor which benefits every agent. Results are shown in Table 2.2.

Even if the vendor adjust his investment level given the number of PM required by the client, there is still a better configuration for the chain. To achieve the maximum NPV for

FIGURE 2.8. Initial Investment Effect over the desired number of PM for the chain.

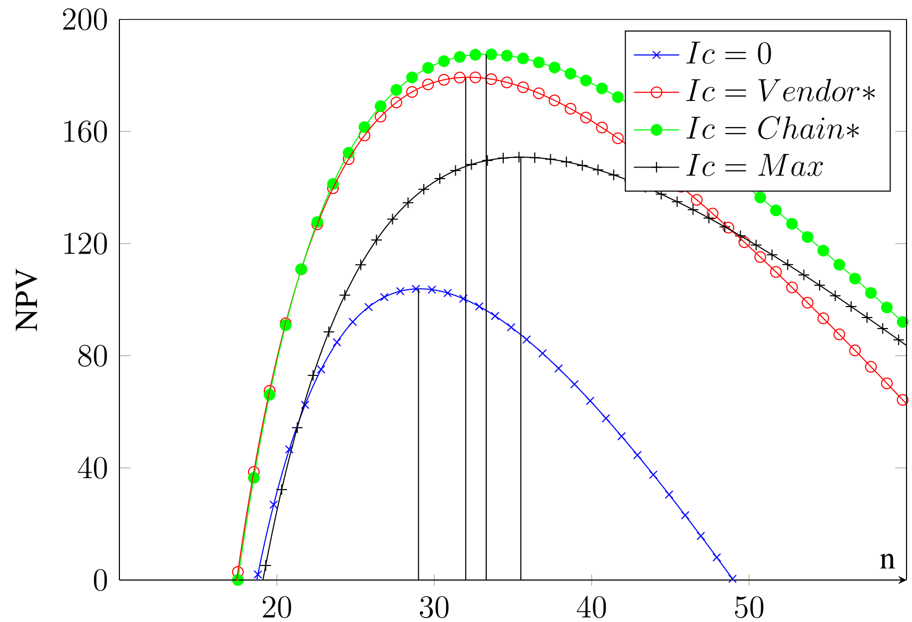
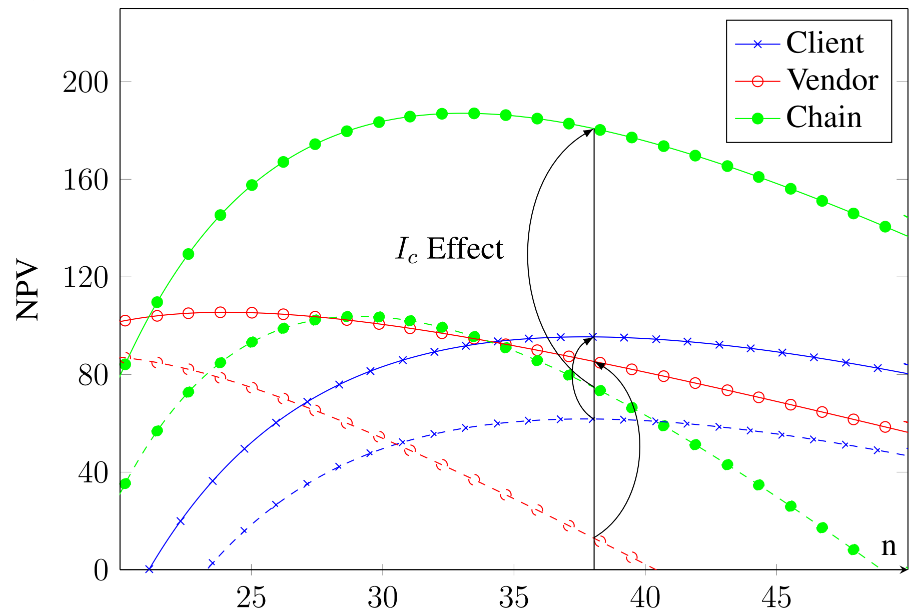


TABLE 2.2. Expected NPV changes due the initial investment level in the uncoordinated case (second column) and coordinated case (third column).

	Initial Case $n = 38$, $I_c = 0$	Base Case $n = 38$, $I_c = 18.1$		Coordinated Case $n = 33$, $I_c = 18.1$	
Party Member	Initial NPV	NPV Value	Change	NPV Value	Change
Client	61.8	95.4	54.5%	95.4	54.5%
Vendor	13.2	85.4	549.7%	91.7	596.9%
Chain	74.9	180.9	141.4%	187.0	149.7%

the entire chain, the client is required to reduce the number of PM interventions. Since his optimal NPV will be reduced by such action, the vendor will have to compensate him with at least the amount of value equal to his loss using a coordination mechanism. In order to analyse how the vendor can transfer some value to the client for accepting a suboptimal number of PM, we will analyse the case of changing the percentage of the cost reduction benefit received by the vendor γ. Figure 2.10 shows the possible combinations of n and γ which keeps the client's NPV constant (NPV=95.4). This results shows that the vendor needs to increase the shared benefit to 7.81%. By doing so, he will be sharing enough benefit to compensate the client loss by performing $n = 33$ interventions instead of his optimal

FIGURE 2.9. Initial Investment Effect. Dashed line: Base case without investment. Continuous line: Vendor defines his optimal investment level for $n = 38$ ($I_c = 18.1$).

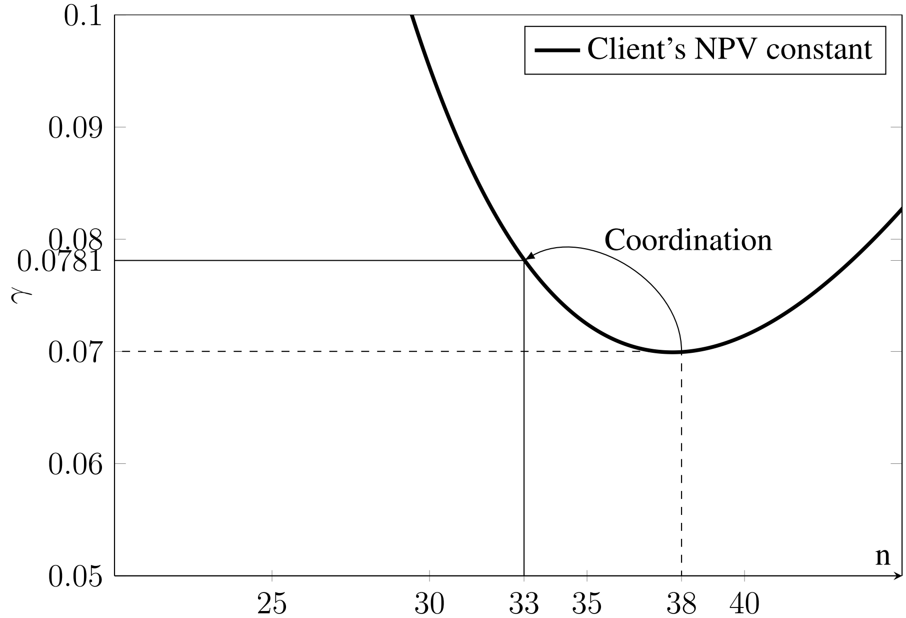


number of $n = 38$. This effect is shown in Figure 2.11.

When the client accept a suboptimal number of PM ($n = 33$) by receiving an additional price discount ($\gamma = 7.81\%$). The chain will increase his expected benefits even more than the uncoordinated case. The right column in Table 2.2 shows the coordination effect over the expected benefits from the contract for each party member.

Since the initial investment level has an impact on the vendor's benefit from the contract, he will be looking towards a contract which consider his optimal investment level and number of PM interventions. On the other hand, since the client NPV is directly affected by the number of PM, he will try to enforce a contract were his optimal number of interventions is performed. Since the optimal decisions by the vendor and client are different,there is a trade-off between these two variables that must be considered while defining the contract terms.

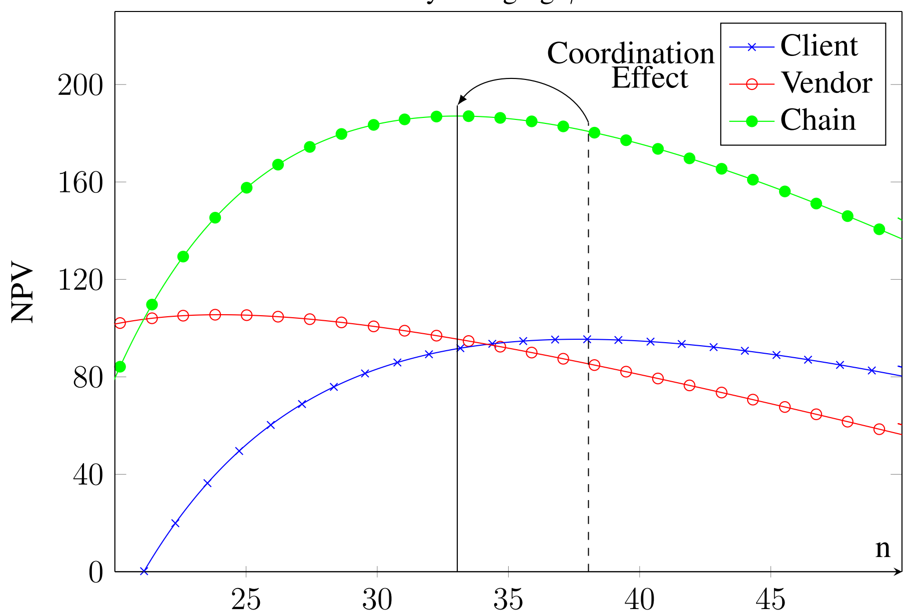
FIGURE 2.10. Coordination mechanism. Combinations of γ and n to maintain client's NPV ($NPV = 95.4$). Dashed line: initial case with $n = 38$ and $\gamma = 7\%$. Continuous line: coordination at $n = 33$ and $\gamma = 7.81\%$.



Results indicate the need for a cost subsidiazation mechanism from the vendor to the client in order to align both interests and prevent the case where each one maximizes its own profit. These incentives can be in the form of revenue-sharing contracts Cachon and Lariviere (2005) where parties share part of their revenue or by reducing the payment to the vendor. A mechanism of compensating the client for his losses can be in form of reduction of the price of the PM. Which in our case is given by the percentage of cost reduction that the vendor transfers to the client given by γ. By doing this the client will require less number of PM interventions and vendor will perform a larger initial investments in technology and hence, the optimal number of PM for the chain will be achieved.

One can also analyse how different functional forms for the cost reduction due the initial investment affect the previous results. In order to obtain these results one can adjust the value of the b parameter and evaluate the initial investment effect for different cases. Table 2.3 shows these results. When the relation becomes more proportional (b closer to 1) the effect over the vendor's NPV is negative. To explain this in Figure 2.7 we can

FIGURE 2.11. Chain Coordination. Dashed line: Initial number of PM. Continuous line: Coordinated number of PM by changing γ to 7.81%.



observe that as the cost reduction becomes more proportional to the invested amount the optimal I_c which maximizes the received cost reduction benefit for the vendor becomes higher. But when considering the benefit and the costs of the contract for the vendor a more proportional cost reduction policy implies such a higher inversion that the benefits doesn't compensate the initial cost.

TABLE 2.3. Technology effect over the expected benefits from the contract when the client defines the number of PM, and the vendor defines his optimal investment level.

	b = 0.2		b = 0.5		b = 1	
Party Member	NPV Change	Change	NPV Change	Change	NPV Change	Change
Client	33.6	54.5%	30.1	48.8%	47.4	76.7%
Vendor	72.3	549.7%	40.5	307.8%	27.2	207.1%
Chain	105.9	141.4%	70.6	94.3%	74.6	99.6%

2.6. Conclusion

This article introduces a model which determines the expected NPV for each party member (vendor, client and entire chain) in presence a performance based maintenance contract. The model adds the possibility for the vendor's option to incur in an initial investment in technology in order to reduce his operation costs associated to each PM intervention.

Early technology investment may possibly increase the expected NPV of the parties involved in maintenance service contracts, but is not guaranteed. Over-investing will result in an unprofitable business for the vendor, as the cost reduction on each maintenance intervention will not compensate the initial expenses. On the other hand, under-investing will not make the contract more attractive. Hence, determining the optimal initial investment becomes imperative to achieve a win-win situation between the client and its vendor viewed as a chain.

The proposed model shows that under a fixed term contract with an initial investment in technology which reduces the PM costs, the vendor and the client will have different optimal configurations that maximize their own benefit. The client has an specific optimal PM interventions number, but will always prefer the highest investment as possible from the vendor because he will obtain a higher price reduction. On the other hand, as the vendor will is paying the initial investment he will have an optimal investment level required to maximize his benefit given a required number of interventions by the client. The vendor's optimal investment level depends on the return over technology investment (b), the cost reduction gap (R) and the discount rate (θ).

There is also an optimal configuration that maximizes the combined benefit, considering both parties as a chain. In order to align interests and change to another configuration, this work proposes a coordination mechanism in which the vendor reduces the PM price or shares part of his revenue with the client. The purpose of this bonus is to at least compensate the client for his losses and hence, accept a contract which would not be his optimal choice but maximizes the chain's benefit. Thus, both parties achieve a Nash Equilibrium where none of them has incentives to deviate from the contract terms.

The present model may be expanded by considering multiple renovations of the contract, where the initial investment is paid at the beginning of the first contract and will affect the future renovations. Also a future research may analyse the effect of an exit clause in the contract, which forces the client to pay an additional fare if he wants to stop the contract before the contract ends. Finally, the model may be expanded to evaluate the scenario where the vendor can use the acquired technology in more than one contract with different clients.

3. GENERAL CONCLUSIONS AND FURTHER RESEARCH

We have developed a methodology that industries can use in the definition and negotiation of performance based maintenance contracts to evaluate different contract configurations and determined the terms which maximize the overall benefits for themselves and their providers. This is particularly useful for asset intensive industries such as mining and can be extended to any performance based maintenance service provider company, so they can evaluate an investment opportunity before providing the service.

Results show that the investment levels have an effect on the optimal number of interventions for each party member. There is a maximum investment level and number of PM interventions for the vendor, which if exceeded will reduce the value of contract for the vendor. For the case of the client, since the vendor always transfer part of the investment benefits and has no cost, he will always look to the highest possible level of investment from the vendor.

As show in Figure 2.2, the optimal number of PM interventions is different for each individual party. Even if one of the members decide all the contract terms maximizing his own benefit, the overall benefits obtained by both parts will not be maximum. We provide a methodology to evaluate and define the contract in order to maximize the entire SC benefit. The proposed approach must be considered while negotiating the contract terms in order to obtain the higher benefits for both members.

A supply chain coordination mechanism must be implemented in order to assure that both parties interests are aligned and maximize the chain benefit. This can be done through a revenue sharing policy where part of the benefit obtained by one party is passed to the counterpart. To achieve this coordination the client can offer an incentive to the vendor to compensate the loss for not being on his optimal. This incentive will be returned by the additional benefit that the client obtain from the chain's optimal contract configuration.

With this new tool the contract negotiation process can consider an initial investment in technology and evaluate its benefits for each party member. Significant cost reduction and efficiency improvements con be obtained by coordinating the parties so the value can be maximized.

Further research is needed to analyse the scenario of complete service delivery and performance payment is used. In this case the equipment and it maintenance are provided by the vendor and the client pays according to a performance indicator defined by the incumbents. Other studies can include different payment structures, e.g. a payment which depends on the provided service level. The case of asymmetry of information can be studied to analyse how the contract decision making process changes in the case of parties that share only part of the information.

Other research can consider different maintenance models, where the contract considers flexibility to change the maintenance politics during the contract or a co-investment structure where both the client and vendor share the initial investment cost. By doing these the cash flow structure will vary and also the commitment of the involved party. Also, there is an opportunity to evaluate different chain coordination mechanism that can move the optimal contract terms for each party, and by doing these align the members to the optimal contract structure.

The model can be expanded to analyse the effect of the initial investment in presence of contract renovations. As the initial investment will be paid only at the beginning, there could be a minimum required contract renovations in order to make the contract profitable for the vendor. A variation to this scenario is the case when the adopted technology can be used in more than one contract with the same client or with different clients at the same time.

The presented work provides a different perspective on performance based maintenance contracts, by considering an initial investment option and its effects in the contract decision making process. The results show the existence of optimal contract terms for the involved parties. Further analysis are required to include more complexities in the outsourcing process.

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