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Joint determination of lease period and preventive maintenance policy for leased equipment with residual value

Wen Liang Chang [a,*], Hui-Chiung Lo [b]

[a] Department of Information Management, Cardinal Tien College of Healthcare & Management, Taipei, Taiwan
[b] Department of Business Administration, Tamkang University, Tamsui, Taipei, Taiwan

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ABSTRACT

This paper investigates the influence of the length of the lease period on the maintenance policy for leased equipment with residual value. The length of the lease period increases, however, the lessor's income increases, and the maintenance cost of the equipment rises as well. Therefore, the lease payment and maintenance service of the equipment are crucial items in the lease contract for the lessor's profit. If the equipment breaks down within the lease period, minimal repairs will be performed on the equipment and the lessor may incur a penalty cost if the repair time exceeds a pre-specified tolerable time. The imperfect preventive maintenance (PM) actions are carried out when the age of the equipment reaches a controlled-limit during the lease period. Under this maintenance scheme, the mathematical model of profit is constructed and then the optimal maintenance policy and the length of the lease period are obtained such that the expected total profit is maximized. Finally, numerical examples are given to illustrate the effects of the optimal length of the lease period and the maintenance policy for profit model.

1. Introduction

Facing highly competitive markets, most enterprises may need complex or multi-functional equipment to provide a variety of products and services to meet the divergent needs of customers. In addition, due to diversification of financing methods, the concept of tax saving is gradually valued by enterprises (lessees). Therefore, many enterprises begin to use finance leasing (that is, capital leasing) to reduce investment risk and working capital. Finance leasing means that enterprises pay rent to a leasing company (lessor) for the leased equipment, and then the lessor offers the equipment and the maintenance service. Hence, a finance leasing contract usually contains the specific length of the lease period, the rent and the penalty clauses. The penalty clauses state that the lessor would be penalized when the leased equipment could not carry out its intended performance according to some specified requests by the lessee. For example, a penalty incurs when the number of failures of the equipment during the lease period or the repair time of the equipment exceeds the specified tolerance limits. Therefore, a well-designed structure of the lease contract and the maintenance plan of the leased equipment are very important issues for the lessor to obtain high profit.

In general, the rent usually depends on the length of the leased period and the specified maintenance service required by the lessees. A longer length of the leased period is expected to increase the revenue of lessors, and the maintenance cost of the equipment rises as well. For reducing the repair cost and the penalty cost, some lessors undertake preventive maintenance (PM) actions to reduce the number of the equipment failures within the leased period. In addition, because of various reasons such as environmental concerns, shortage of material, economic benefit, and legislative pressure, re-use has been receiving growing attention and the reclaiming channels are gradually increasing. Therefore, some lessors take the residual value of the equipment into account when they are considering the length of the leased period. For instance, car rental companies sell their used cars to the second-hand markets and most of these cars have been sold by the time they are 2 years old (Pongpech & Murthy, 2006).

As mentioned above, this paper proposes a leasing model of the durable and repairable equipment for lessors. The motives of the leasing model are to provide a PM scheme to reduce the total cost within the lease period and to consider the income from the residual value of the equipment at the end of the lease period. Therefore, taking the factor of the residual value of the equipment into account, this paper aims simultaneously to determine the length of the lease period and the PM scheme in the lease contract for the lessor so that the expected profit is maximized.

The remainder of this paper is as follows. Section 2 includes a literature review about leasing and maintenance policies. The

* Corresponding author. Tel.: +886 2 22191131; fax: +886 2 22198074.
E-mail addresses: D9101402@mail.ntust.edu.tw (W.L. Chang), hclo@mail.tku.edu.tw (H.-C. Lo).

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proposed model of this paper is described in Section 3. In Section 4, the optimal PM policy and the length of the lease period are obtained and an algorithm is constructed to organize the solving processes. Some numerical examples are offered to illustrate the leasing decisions and the results are compared with different situations in Section 5. Finally, conclusions are drawn.

2. Literature review

In this section, we provide a brief literature review on leasing and maintenance policies, and mainly focus on papers with decision making of preventive maintenance policies in a leasing environment.

As the usage and age of the equipment increase, the failure rate of the equipment often increases. Therefore, maintenance on the equipment is necessary to avoid the interruption of production processes of goods/services. There is a vast literature dealing with optimal maintenance policies (Valdez-Flores & Feldman, 1989; Wang, 2002, 2006; Wang & Pham, 2006). In general, maintenance planning can be first classified into corrective maintenance (CM) and preventive maintenance (PM). CM rectifies failed equipment back to its operational status, whereas PM improves the operational status of the equipment. In addition, according to the degree to which the operating condition of the equipment is restored by maintenance, each of the CM and the PM can also be classified into five grades (from highest to lowest): perfect, imperfect, minimal, worse, and worst (Wang & Pham, 2006). For CM, minimal repair is the most commonly used corrective maintenance. Nakagawa (Nakagawa, 1981) used minimal repair to restore failed equipment back to operational status and the failure rate of the equipment remains unchanged after performing a minimal repair. Various maintenance models involving minimal repair can be found in the literature (Barlow & Hunter, 1960; Boland & Proschan, 1982; Chiu & Chiu, 2006; Jhang, 2005; Nakagawa & Kowada, 1983). For repairable equipment, PM actions are widely employed to reduce the number of equipment failures since the cost for carrying out a planned PM action is usually less than the cost incurred by an equipment failure. Various PM models have been proposed for different situations such as periodical or sequential PM (Nakagawa & Kowada, 1983; Sheu, 1991; Valdez-Flores & Feldman, 1989), and perfect or imperfect PM (Jack & Dagpunar, 1994; Nakagawa, 1979; Pham & Wang, 1996).

Furthermore, for the quantitative description of the effectiveness of the imperfect PM, three methods are considered in the maintenance model: (i) age-reduction method (ARM), in which the age of the equipment is restored to the one younger than the current age after each PM action, e.g. (Jack & Dagpunar, 1994; Yeh & Lo, 2001), (ii) failure-rate reduction method (FRRM), in which the failure rate of equipment is reduced after each PM action, e.g. (Jaturonnatee, Murthy, & Boondiskulchok, 2006; Yeh, Kao, & Chang, 2009), and (iii) hybrid method, the combinations of the above two methods, e.g. (Zhang & Jardine, 1998). However, Wu and Zuo (2010) attempted to review the existing PM models and explore the interrelationships of these models. They further categorized these models into three classes: linear, nonlinear, and a hybrid of both.

Based on the reasons that newer and better equipment appears on the market and that the cost of owning the equipment is increasing, more businesses have started leasing equipment rather than owning it (Pongpech & Murthy, 2006). Therefore, there is also a growing literature in the decision making about the lease contract. Nisbet and Ward (2001) introduced the processes of purchasing and leasing radiotherapy equipment in Raigmore Hospital in UK. They then dealt with the choices of either purchasing or leasing radiotherapy equipment. In addition, there exists the literature focusing on decision making in the pricing of lease contracts. For instance, Huang and Yang (2002) investigated the pricing of lease contracts for the durable equipment, such as cars, furniture, computers, and other electronic appliances. Aras, Güllü, and Yürülmez (2010) considered a business situation in which a company leases new equipment and sells the remanufactured one at the same time. Under the business model, they developed a dynamic program formulation to determine the optimal price of the remanufactured equipment and the optimal payment structure for the leased equipment to maximize the profit.

On the other hand, some researchers studied various PM policies to reduce the cost for the lessors. Jaturonnatee et al. (2006) developed a sequential PM scheme using FRRM and derived the optimal number and degree of PM for leased equipment with minimal repairs. For practical needs, Pongpech and Murthy (2006) and Yeh et al. (2009) used different strategies to reduce Jaturonnatee's scheme. Pongpech and Murthy (2006) considered a periodical PM scheme with various maintenance degrees, whereas Yeh et al. (2009) proposed a sequential PM scheme with the fixed maintenance degree. Yeh and Chang (2007) found the optimal threshold value of failure-rate and maintenance policy within the lease period. Hu and Zong (2008) relaxed the condition under which the length of the lease period is given in the model of Pongpech and Murthy (2006), and determined the optimal length of the lease period and optimal PM scheme to minimize the total cost per unit time. For used equipment, Pongpech, Murthy and Boondiskulchock (2006) investigated the optimal upgrade level before leasing and optimal PM scheme within the lease period.

However, most of the studies mentioned above did not investigate the optimal length of the lease period in the lease contract; instead they only focused on determining the optimal PM policy for leased equipment with a specified leased period. Furthermore, all of these papers utilized FFRM to build cost models to determine the optimal PM scheme, but they failed to take into account the residual value of the equipment after the lease period. Therefore, based on the viewpoint of the lessor's profitability, this paper adopts ARM to describe the degree of PM for leased equipment and builds a profit model by considering the residual value. Moreover, a mathematical model of the expected total profit within the lease period is constructed and the optimal maintenance policy and the length of lease period are so obtained such that the expected total profit is maximized. At the end of Section 5, an example is given to illustrate the practical applications of our model.

3. Proposed model

We used the following notations in this paper:

L	lease period
V	the purchase price of the equipment
t_d	life cycle of the equipment
V_d	residual value of the equipment at time t_d
W	the lease payment per unit lease period of equipment
$f(t)$	probability density function of the lifetime of the leased equipment
$h(t)$	failure rate function of the leased equipment
$H(t)$	cumulative failure rate function of the leased equipment
C_r	minimal repair cost
t_r	time required for performing a minimal repair
$G(t_r)$	cumulative distribution function of t_r
τ	pre-specified time limit for carrying out a minimal repair
C_τ	penalty cost if the minimal repair time exceeds the time limit τ