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Option model for joint production and preventive maintenance system

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ABSTRACT

Traditionally, optimal preventive maintenance strategies are derived under deterministic and constant rate demand. Using "option", a powerful financial derivative tool to tackle optimization problem under uncertain environment, this paper presents an analytical, option-based cost model for scheduling joint production and preventive maintenance when demand is uncertain. The manufacturing enterprise can balance the tradeoff between reduced risk from uncertainty that options afford and the increased price premium paid to invest preventive maintenance resources. The optimal number of preventive maintenance work-orders is obtained and numerical examples are included to validate the importance and the effectiveness of the proposed methodology. The comparison with the conventional periodic preventive maintenance policy is also analytically performed. The proposed option-based model is found to add flexibility to the production system and thus reduce the risk of shortage or overage of demand when conventional assumption of constant rate demand is released to stochastic demand.

1. Introduction

The rapid changes in markets, the increasing uncertainty in customer demands, and the unexpected failures in unreliable machines have raised the cost of manufacturing in the current fast-paced industrial environment. To meet the uncertain future demands and to ensure the economic success of a production system, cost-effective and reliable production planning and maintenance scheduling is required.

The maintenance policies currently used in the industry are generally classified into reactive maintenance (RM, or corrective maintenance) and preventive maintenance (PM). RM is performed once a machine breaks down. The main task of such maintenance activities is to restore the machine to a desired condition. PM is like a "scheduled or planned machine breakdown" and it is defined as the maintenance work-orders performed on a machine while still in its operating state, which would bring the system to the "as good as new" condition (Sheu et al., 2001). It is observed that RM usually results in a higher downtime compared to PM due to unavailability of resources, causing logistic delays. Hence, the general cost of RM may be as high as three to four times as that of PM (Chitra, 2003). A large amount of existing literature has shown that implementing PM strategies in unreliable production facilities can effectively prolong machine life and reduce operating cost (Nakagawa and Yasui, 1991).

Generally, the risk of production and maintenance system can be managed both operationally and financially. Conventionally, PM policies implemented in manufacturing enterprise systems are operational-oriented. Operationally, an enterprise can do inventory-driven PM strategy, condition-based PM policy and time-triggered maintenances etc. There are numerous papers on operationally optimizing inspection and maintenance in

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production systems in the presence of machine failures. These optimization models are usually developed under consideration of production metrics such as throughput, reliability, availability and overall cost of a system. Srinivasan and Lee (1996) considered an (*s*, *S*) PM policy in which the PM work-orders are performed as soon as inventory reaches a certain threshold value, *S*. They formulated PM and safety stock strategies assuming that the PM tasks are scheduled every *m* units of time and derived *m* by minimizing expected cost per unit time. Sim and Endrenyi (1988) developed a minimal preventive-maintenance model where the optimal value of mean time for PM policy is determined by minimizing the unavailability of the machine due to machine break-downs. Meller and Kim (1996) considered a control policy where the system undergoes repair once it breaks down. The production resumes immediately after repair, continuing until the inventory level reaches a threshold value. Dohi et al. (2001) extended the economic manufacturing quantity (EMQ) model by Cheung and Hausman (1997) to a new stochastic PM model to find an optimal policy, in which manufacturing quantity and safety stock are derived minimizing the cost per unit time. Kenné et al. (2007) formulated an analytical model for the joint determination of an optimal age-dependent buffer inventory and PM policy in a production environment that is subject to random machine breakdowns. Castro (2009), Zequeira and Bérenguer (2006) determined the optimal preventive maintenance schedules by considering two modes of failure (maintainable and non-maintainable) and the number of PM tasks are dependent on different failure rates of the system.

For operational maintenance planning, maintenance policy is usually time-triggered or periodical, which is either inefficient or excessive. It may happen that a PM task is scheduled right after the machine just resumes. High cost arises due to the unnecessary scheduled down-times and expensive restoration. Another limitation of the maintenance policies presently implemented is the ignorance of the real dynamics of market demand, and lack of flexible mechanism to make a prompt response to a rapidly changing demand. Most of the researches focus on long-term planning policies that provide steady state plans, assuming that production systems have deterministic demand with constant rate (Lee and Rosenblatt, 1987; Groenevelt et al., 1992). Nevertheless, it is infeasible for the consumer industries with short product life cycle in today's fast changing market.

In comparison to the rich and abundant literature available on operational planning and managing production and maintenance, seldom literature addresses the financial instrument to exploit intelligent strategies for an integrated production and maintenance system. Unlike conventional operational maintenance models, the novel idea of this paper is to incorporate financial engineering concept "option" into a manufacturing enterprise system to deal with the limitations abovementioned. Options will be rigorously applied to evaluate the joint production and maintenance system in order to effectively find the optimal maintenance policy.

The term "option", originally a financial derivative, is defined as a "financial instrument whose payoffs and values are derived from or depend on something else" (Ross et al., 2002). An option is a contract giving the owner the "right but not the obligation" to buy or sell an asset at a fixed price before or on a future date. The term "real option", coined by Myers (1977) and Copeland and Antikarov (2001), is defined as "the right but not the obligation to take an action at a predetermined cost called exercise price for a predetermined period of time". In recent studies, many attempts have also been made to apply an option or real option to other areas such as manufacturing/production system. Bengtsson (2001) reviewed manufacturing flexibility and real options from an industrial engineering and production management perspective. The value of option-based flexibility is considered at three levels: machine level, production system level, and manufacturing plant level.

In this paper, option is defined as the right of manufacturers to produce additional units at a lower price since PM can improve reliability and production efficiency. The manufacturing enterprise can balance the tradeoff between reduced risk from uncertainty that options afford and the increased price premium paid to invest PM resources. The proposed option-based PM policy can provide flexibility to adjust production output to satisfy the demand requirement. In this paper, the preliminary contribution is to introduce the new concept of "option" to formulate a joint production and maintenance system, and to extend the conventional periodical maintenance model to an option-based PM model with stochastic demand. The option described in this paper is an instrument derivative whose value is linked to demand uncertainty, which is easily modified to study options whose value is related to other uncertainties of manufacturing system. Using such options that increases the flexibility of the manufacturing operations and decreases the risk due to demand uncertainty, two main improvements can be addressed: (i) PM policy is changed from fixed periodical one to flexible one and (ii) conventionally deterministic demand is extended to uncertain demand.

The rest of this paper is organized as follows. In Section 2, an option-based PM optimization model is formulated and optimal decisions are derived. Section 3 discusses some important relationships among the cost parameters. Section 4 presents numerical studies. Finally, the conclusions and future work are given in Section 5.

2. Problem formulation and preliminary results

In modeling, we assume the production and maintenance decision can only be made at the beginning of production period. In addition, the deterioration of machines is assumed to be linearly increasing with the times of machine breakdowns.

Notation	Description
D	demand per period, supplied by the inventory
α	production rate (speed)