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Joint optimization of preventive maintenance and spare parts inventory for an optimal production plan with consideration of CO_2 emission

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ABSTRACT

This article presents a joint optimization of spare parts inventory and preventive maintenance. While minimizing CO_2 emissions, this approach is based on an optimal production plan achieved thanks to the HMMS model. The process which is studied in this paper only manufactures one type of product. The purpose of the paper is to determine for a random demand over a given period, a cost-effective production plan and a maintenance policy which integrates a spare parts strategy in accordance with environmental requirements and regulations. Our green spare parts management can be defined as a set of actions that are applied in order to decrease the spare parts footprint in its lifetime (Ba et al., 2015) [1]. Indeed, we take into account the spare parts characteristics (new or used) which will be used during maintenance actions (preventive or corrective) to preserve the environment. Consequently, we set up analytical models based on the effect of the production rate on the system deterioration so as to substantially cut the maintenance costs, production costs and CO_2 emissions. To evaluate the performance of our models, we give some illustrative examples.

1. Introduction

Global industrial competition has made it compulsory for companies to offer their customers high-quality products and at the same time to cut their costs and their CO_2 emission in order to meet international regulations. In order to address this challenge, companies must set up a reliable production system and develop a management policy with focus on the environmental impact [2]. That is the reason why new optimal maintenance strategies are essential [1]. Maintenance of production equipment is an issue which has always raised considerable interest in the scientific community. Chang [3] also dealt with the reliability theory. He proposed to determine the optimal date of preventive maintenance considering the minimal repair, the replacement and the working times. He considered two cases: repairable and non-repairable items in order to reduce the global cost.

We find in the literature different maintenance policies for one-unit systems such as: failure limit policy [4], cost repair limit [5], sequential policy [6,7] or repair number counting and reference time policy [8].

Nakagawa set up the block-type strategy, which is often applied for its ease of use. In this strategy, the system is replaced by a new system in accordance with a fixed plan T, $2T$,…,NT [9]. Barlow and al came up with a policy based on age. In this policy the equipment is replaced after a fixed lifetime or following a breakdown [10].

However, a maintenance policy can only be fully effective if it is combined with an efficient policy of spare parts inventories [11,12]. Therefore, the implementation of optimal spare parts inventories is critical to maintenance efficiency. Issues regarding optimal order quantity, frequency, service continuity and cost saving techniques must be addressed [13]. Chelbi and Aït-Kadi [14] dealt with the issue of jointly spare parts provisioning strategy and optimal replacement date for a system where failures occur randomly. They proposed a mathematical model in order to implement their replacement strategy. This strategy considers the requirement in spare part and the probability distribution of the equipment in a reordering cycle. Jin et al. [15] proposed a policy which jointly optimizes the inventory of spares, the capacity of repair and the maintenance under the game-theoretical framework.

Panagiotidou [16] proposed two ordering policies to supply the necessary spare parts for multiple identical items subject to silent

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failures: a continue review and a periodic review policy. These strategies are based on a joint optimization of maintenance and spare parts ordering policies.

Moreover, strategies used in spare parts inventories will differ from those in use in the Work In Process stocks [11]. Van Jaarsveld et al. insisted on how pivotal spare parts management were within the scope of a maintenance strategy [17]. In addition, it is very hard to evaluate the shortage costs for spare parts.

Industrials and the scientific community understood very quickly that strategies dissociating production and maintenance were less efficient. To achieve these objectives of cost reductions it is necessary to considerably improve policies of tools management. We find in the literature different management policies considering the maintenance of the equipment as well as the production like:

a. The first category presents models of simultaneous optimization of maintenance and production rate as proposed by Charlot [18], and Kenne [19]. In these models, the production rate and the dates of maintenance represent variables of decision for a technical–economic optimization.
b. A second category of models relates to the systems of production where there is a buffer stock, Kyriakidis [20], Gharbi, [21]. In these models, a buffer stock is set up in order to reduce the impact of the breakdowns on the productivity and to satisfy the request of customers during the periods of preventive maintenance.
c. The third category of models relates to EMQ models (Economic Manufacturing Quantity) as proposed by Cassady [22] and Wang [23]. These models are based on the study of the failures of the system of production and their impact on the dimensioning of batches (batch sizing).
d. The last category of models focuses around the aggregated problems in which variables of decisions of maintenance (preventive and/or corrective) and production can be used in the same economic function. We remind for example studies presented by Lu [24]. Hajej et al. [25,26] proposed a method and models to determine in the first instance the optimal production plan (linear-quadratic stochastic programming, HMMS of Holt) and then, using this optimal production plan they establish the optimal maintenance plan. The special characteristic of this work is the consideration of the impact of the production plan in the implementation of the maintenance plan. Liu et al. [27] proposed recently an aggregated preventive maintenance, inventory and production model for a system which produces multiple products.

Moreover, Nourelfath et al. [28] dealt with the issue of planning maintenance actions and production plan for a manufacturing system comprised of parallel components. Nourelfath et al. added two factors: the common cause of breakdowns and the economic dependence of systems in parallel [29]. It is obvious that the latest model significantly improves the classical maintenance strategies.

Therefore, the traditional approach which dissociates maintenance and production is not satisfactory. In our work, we set up analytical models considering the incidence of the production plan on the system deterioration so as to substantially cut maintenance costs, production costs and CO_2 emissions.

The rest of the document is structured as follows: In Section 2, we remind the environmental issues, challenges and the different tools available for an ecologic approach. In Section 3, we describe the problem. Then in Section 4, we propose a cost-effective production plan (linear-quadratic stochastic programming, HMMS of Holt) and a numerical example is provided. In Section 5, we set up analytical models based on the impact of the production plan on the system deterioration so as to reduce the maintenance costs. Afterwards, we propose in Section 6 three different models to reduce the management costs and the CO_2 emissions of the spare parts. Next, the forcefulness of models is demonstrated in a sensitivity study in Section 7. Finally, in Section 9, we conclude our work and suggest some prospects.

2. The environmental issues and challenges

Some products are unconsciously believed to be harmless. Indeed, the environmental impact is often ignored by consumers and even by some industrials. Farming and industrial activities are proven to cause pollution and greenhouse gases. The new challenge for both governments and private industries is to reduce their gas emission in order to stop global warming. Industrialized countries are committed to respecting the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC). It is an international treaty whose final goal is to press industrialized countries to cut their CO_2 rejections into the atmosphere [30]. ADEME (French Environment and Energy Management Agency) proposes the Carbon Assessment, the first French software quantifying greenhouse gas emissions. It is a technical tool that evaluates the carbon footprint of a product. The Carbon Assessment enables the counting of emissions of direct and indirect greenhouse gas from an activity or a product. Fig. 1 presents the carbon emissions throughout the lifetime of the spare part.

The data about the Rotor HH-100 are provided by ADEME. Fig. 2 presents the carbon footprint of this part and Table 1 shows a comparison of the carbon footprint between a new and a used spare part and Fig. 2.

In green on Fig. 3, you can see the carbon rejected by a used spare part during its lifetime. We observe that a used spare part releases only 3% of the quantity of CO_2 released by a new spare part. Indeed, the steps releasing the most CO_2 do not exist for the used spare part: fossil fuel used in raw material extraction, raw material and manufacturing.

Based on those studies previously cited we are confident that we can establish new environmental-friendly maintenance strategies by adding the possibility to execute maintenance action with used spare parts. Moreover, used spare parts offer many advantages: loose buying (less packaging), cost-effectiveness, ecological (neither manufacturing nor assembly).

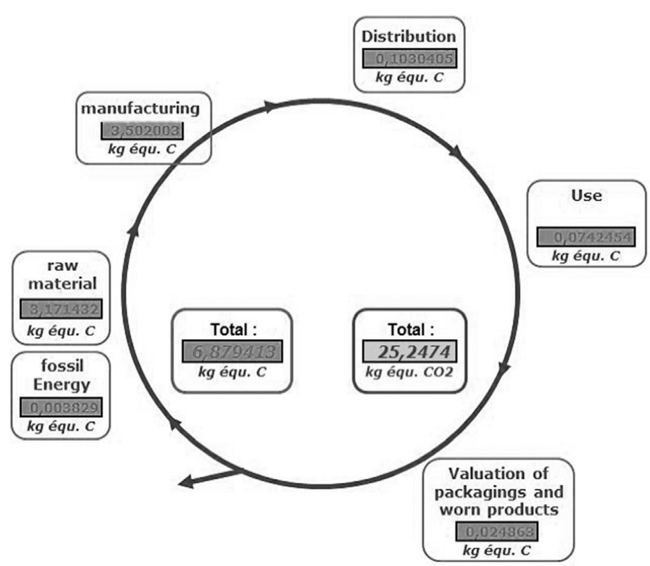

Fig. 1. Carbon emissions throughout the lifetime of the spare part.