Joint maintenance and inventory optimization systems: A review

Adriaan Van Horenbeeka, Jasmine Buréa, Dirk Cattryssea, Liliane Pintelon a, Pieter Vansteenwegen b, *a

Centre for Industrial Management, Traffic and Infrastructure, KU Leuven, Belgium
Department of Industrial Management, Ghent University, Belgium

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A B S T R A C T

During the past decades, several joint maintenance and inventory optimization systems have been studied in literature. Compared to the sequential optimization of both models, Kabir and Al-Olayan (1996) reported a remarkable influence on total cost due to their joint optimization method. This review focuses on models that include cost and optimization parameters related to both maintenance and inventory. The purpose of this paper is to review the pertinent literature on joint maintenance and inventory optimization models for non-repairable parts and suggest possible gaps. A classification based on the following seven sets of criteria is made: inventory policies, maintenance characteristics, delays, multi-echelon networks, single-unit versus multi-unit systems, objective function and optimization techniques.

1. Introduction

The main reason a company keeps an inventory of spare parts is to perform maintenance in order to restore the system in such a way that it can perform its intended function. The number of spare parts in inventory is determined by the demand, caused by corrective as well as preventive maintenance, for each spare part. Maintenance relies on the availability of spare parts in order to reduce failure downtime and costs. It is clear that maintenance and inventory management are strongly interconnected and should both be considered simultaneously when optimizing a company’s operations. During the past decades, several joint maintenance and inventory optimization systems have been studied in literature. Compared to the sequential optimization of both models, Kabir and Al-Olayan (1996) reported a remarkable improvement on total cost due to their joint optimization method. Several reasons can be found for this cost reduction. On the one hand, maintenance models often rely on the assumption of an inexhaustible number of available spare parts (e.g. Barlow and Hunter, 1960) and on the assumption that these are available without any lead time (Dohi et al., 1998). These assumptions are not always realistic and it would be too expensive for a company to sustain such a system. On the other hand, the unilateral focus on the inventory policy might result in higher costs for maintenance (Acharya et al., 1986). The joint optimization of spare parts and maintenance takes into account the trade-off between maintenance and inventory policies.

This review focuses on papers that include costs (e.g. inventory and maintenance costs) and optimization parameters (e.g. ordering time, replacement time, etc.) related to both maintenance and inventory management. As far as the authors of this paper are aware, this is the first review paper on joint maintenance and inventory optimization taking into account both the costs and parameters related to maintenance and inventory. Another interesting review paper on the joint optimization of maintenance and inventory policies was written by Dohi et al. (1998), but in the end only inventory related costs were included in the models reviewed in their paper. Searching Web of Science and Google Scholar using the keywords ‘maintenance’, ‘inventory’, ‘replacement’ ‘joint’ and ‘ordering’ gave us the majority of the papers. The other papers were found by scanning the references and using the ‘cited by’ option. The scope of our paper is limited to models for non-repairables. If a non-repairable part breaks down, it is removed and replaced by a new part. These non-repairable parts are defined as a ‘unit’ throughout the entire paper. The reader interested in models for repairable spares is referred to e.g. Park and Park (1986); Chiang and Yuan (2001); Sarkar and Sarkar (2001) and de Smidt-Destombes et al. (2009). The purpose of this paper is to review the pertinent literature on joint maintenance and inventory models for non-repairables and to suggest possible gaps that could lead to interesting future work. A classification based on the following seven sets of criteria was made: inventory policies, maintenance characteristics, delays, multi-echelon networks, single-unit versus multi-unit systems, objective function and optimization techniques. Each of them is discussed in the second section. In the third section, the contribution of the
long, it might be interesting to keep more than one part in stock, 
tory. When failure frequencies are high or lead times are very 
time. As an example, let spares be ordered depending on e.g. the forecasted demand of 
spares are ordered depending on e.g. the forecasted demand of 
the next period. As an example, let \( R \) be the length of the review 
interval. In the continuous review policy, the inventory levels 
are checked continuously and when a certain condition is met 
(e.g. the amount of spare parts drops below a certain level), spares 
are ordered. Two well-known and often used continuous review 
policies are the \((S, S)\) and the \((S, Q)\) policy. Using an \((S, S)\) policy, one 
orders spares to reach the order-up-to level \( S \), whenever the 
inventory level drops below \( S \). When \( Q \) units are ordered each 
time inventory drops below \( S \), it is called an \((S, Q)\) policy. When 
there is a per unit demand, both systems give the same result if \( Q \) 
equals \( S \) minus \( s \). A special case of a continuous \((S, Q)\) review 
policy, which is mainly used for low cost and high demand spare 
parts, is a two-bin policy where a replenishment order is placed 
when the first bin is empty. At that time, one starts to use the 
second bin and a new bin is ordered.

In a periodic review policy, at the beginning of each cycle, 
spares are ordered depending on e.g. the forecasted demand of the 
next period. As an example, let \( k \) be the length of the review 
interval. Using the \((R, S)\) policy, one orders up to \( S \) units each 
time at the beginning of the review interval.

Another important inventory characteristic to take into 
account is the consideration of a single-unit or multi-unit invent-
tory. When failure frequencies are high or lead times are very 
long, it might be interesting to keep more than one part in stock, 
even though a single unit system is under consideration. On the 
other hand, keeping multiple units in inventory increases the risk 
of obsolescence. Obsolescence is a major (cost) issue for spare 
parts which are rarely needed for replacement (Kennedy et al., 
2002).

2.2. Maintenance characteristics

2.2.1. The degrees of maintenance

Different degrees of maintenance are discussed in the litera-
ture (Wang and Pham, 1996). When the fixed system is as good as 
new after the maintenance actions, it is called a perfect repair. 
Unfortunately, most repairs do not fix the system perfectly. A 
minimal repair restores the system to an as bad as old state, 
which means that the system has the same failure rate after repair 
as it had just before the repair. Imperfect repair restores the system 
to a state somewhere in between as good as new and as bad as old. 
A less favorable degree of repair is worse repair in which the 
systems condition is worse than just before failure. In some 
circumstances one might even have a worst repair, which means 
that the system breaks down completely after maintenance.

The reason to consider the degrees of maintenance even for 
non-repairable parts, as considered in this paper, is that a 
replacement of a part by a new part can be imperfect too. Wrong 
installation of the part, outlining errors etc. can result in imperfect 
replacement. Moreover, when considering multi-unit systems, 
the replacement of one broken unit does not always make 
the entire system perfect again. A simple example is a bicycle 
wheel, where the entire wheel is seen as a system that consists of 
multiple non-repairable units, the spokes. When one spoke 
breaks, the replacement of it does not result in an as good as 
new system or wheel; it results in an imperfect repair of the 
system. Armstrong and Atkins (1998) make a distinction between 
a major and a minor failure and Nguyen and Bagajewicz (2009) 
assume imperfect preventive maintenance. All other papers 
considered in this review assume that the systems are perfectly 
maintained or do not mention any assumption concerning the 
degree of restoration.

2.2.2. Maintenance strategies

Three major maintenance strategies can be distinguished. The 
most reactive strategy is failure based maintenance (FBM) (also 
called corrective maintenance). Whenever a failure occurs, the 
units are replaced or repaired as soon as possible. If no spare part 
is available, the maintenance is delayed and possibly high down-
times are induced.

A second well known strategy is preventive maintenance. 
Several policies might be classified as being preventive. A review 
is provided by Wang (2002) and a brief explanation of the most 
important preventive maintenance policies for non-repairables, 
considering both single-unit and multi-unit systems, is provided. 
For single-unit system these policies are

- Age-based preventive maintenance: a unit is always replaced 
at its age \( T \) or failure, whichever occurs first, where \( T \) is a 
constant (Barlow and Hunter, 1960).
- Block-based or periodic preventive maintenance: a unit is 
replaced at prearranged times \( kT \) \((k=1, 2, \ldots, n)\) independent of 
the failure history of the system.
- Sequential preventive maintenance: when machines and their 
parts become older, they need more frequent maintenance. To 
take this into account, time intervals become shorter as time 
passes by.
- Failure limit maintenance: units are replaced as soon as the 
failure rate or other reliability indices of a unit reach a 
predetermined level. All failures occurring in the meantime 
are corrected by replacements.
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