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Integrated production and maintenance planning in hybrid manufacturing-remanufacturing system with outsourcing opportunities

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Abstract

This paper deals with the problem of integrated production and maintenance planning with different qualities of returned products and outsourcing opportunities in a closed-loop supply chain context. The considered network consists of one manufacturer in a relationship with an outsourcing provider. The manufacturer is considered as hybrid manufacturing-remanufacturing system. It produces the new products and collects returned ones for remanufacturing activities. The outsourcing provider specializes in the remanufacturing of returned products from the collection and sorting center that the manufacturer is unable to reprocess. We propose an integrated control policy based on mathematical programming, which aims to determine the integrated production and maintenance planning in a hybrid manufacturing-remanufacturing context with outsourcing options. The proposed strategy minimizes the total cost of the system over a finite planning horizon, including manufacturing, in-house remanufacturing, outsourced remanufacturing, maintenance, holding, backlogging, and disposal costs. To show the applicability and validity of the developed model, we implement an iterative procedure using Matlab and CPLEX solver of GAMS. We conduct and discuss computational experiments to investigate managerial insights for the newly developed integrated strategy.

Keywords: Hybrid manufacturing-remanufacturing system; Return; Production; Outsourcing; Imperfect maintenance; Closed-loop supply chain.

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1. Introduction

In a real production environment, machines may produce in a degraded mode and, consequently, fail and become unavailable. When these systems are not operating correctly and require maintenance actions, the products can

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be out of compliance. As a result, customers will be forced to return non-conforming products. In a Closed-Loop Supply Chain (CLSC), manufacturers must be responsible for collecting returned products and reusing or disposing of them. Compared to disposal, remanufacturing is economically more attractive. Teunter et al. [24] state that while remanufactured products are of the same quality as newly manufactured ones, they are not always regarded as such.
Manufacturers may choose to adopt Reverse Logistics (RL) for economic or competitive benefits, or they may be forced to do so due to legislation or environmental concerns, but they must decide whether to conduct the activities themselves or outsource one or more of them to a third-party [2]. Outsourcing can be done for technological reasons, such as when a company lacks the technology to efficiently manufacture an item, or for capacity reasons, such as when a company does not have the necessary capacity to carry out a required demand [6].
Integrated management approaches enable the simultaneous management of multiple areas within an organization. In the past, these areas were optimized separately. To avoid functional conflicts, integrated approaches combine the requirements and objectives of various functions, allowing the organization to become more efficient in achieving the desired targets. By considering the interactions between functions, they provide a comprehensive view of this organization [10]. In this context, the investigation of integrated production and maintenance planning with returns remanufacturing and outsourcing is presently an interesting issue in the fields of RL and CLSC.

The rest of this paper is arranged as follows. In Section 2, a literature review is presented. Section 3 is devoted to describing the problem. Notations, model formulation and resolution approach are demonstrated in Section 4.
Section 5 presents the numerical experiments and discuss the results. The paper concludes in Section 6, where some future directions of the work are discussed.

2. Literature review

When dealing with a CLSC, different decision levels are distinguished, namely, long-term and medium-term decisions are referred to as ”design” and ”planning”, respectively. During planning, the objective is to determine the quantities of flows between the network entities [23]. In the last decades, there have been many discussions about production planning involving combined manufacturing and remanufacturing operations. Teunter et al. [24] proposed a mixed integer programming model of the dynamic lot-sizing problem that includes returned product remanufacturing. Pan et al. [16] extended the problem of [24] by incorporating a disposal option for returned products and restricting manufacturing, remanufacturing, and disposal capacity. Amin et al. [3] explored the remanufacturing of reusable parts where the producer has two options for supplying parts: purchasing the required parts from external suppliers or refurbishing returned items and restoring them to ”as new” conditions.
Although there is a lot of research on joint manufacturing and remanufacturing in separate systems, only a few papers look at Hybrid Manufacturing-Remanufacturing Systems (HMRS), which combine the two processes into one with shared resources. Van der Laan et al.[13] conducted the initial research on the HMRS. The focus of this paper was on inventory control and production planning. Polotski et al. [17] investigated the problem of scheduling with setup costs and setup times in a HMRS consisting of one machine. In other research, [18] considered failure-prone HMRS with varying demand and returns over time. The authors of [14] addressed the issue of optimizing production planning in a sustainable HMRS. This latter is made up of a set of machines that remanufacture products of different grades.

The supply chain is frequently subject to a variety of risks and disruptions (for example, fluctuation in demand, machine unavailability due to breakdowns,etc.) that can compromise delivery reliability. To do so, different practices, such as outsourcing, can be considered in order to deal with disruptions and achieve a reliable supply chain network capable of meeting client demands [9]. In this context, Kim et al. [12] considered in-house remanufacturing of used products. The rest, beyond the in-house remanufacturing capacity, is sent to a subcontractor. Wang et al. [25] addressed the single-item dynamic lot-sizing problem, where the demand may be satisfied by manufacturing of new items, remanufactured items, or outsourcing, but it cannot be backlogged. Using the same logic, Zouadi et al. [28] applied outsourcing decisions of returns procurement in a HMRS.

Over the course of time, the components of an operating system degrade. A machine that is operating in a degraded mode or with incorrect settings can cause breakdowns or produce non-conforming products. From here, an effective maintenance policy is essential to keep the equipment in optimal operating conditions. In recent decades, researchers have enriched the literature on integrated production and maintenance planning. Aghezzaf et al.[1] proposed a model by assuming that the system is subject to random breakdowns. The system is periodically overhauled and minimally repaired at failures. It also assumes that any maintenance action reduces the available production capacity of the system. This work is extended by various researchers, such as [7]. Zhao and Wang [27] used the operation-dependent failure concept to model the integrated problem with unequal time periods. They also proposed an iterative method to approximately solve the model.

In contrast to the previously cited papers focused on perfect Preventive Maintenance (PM), other academics have considered the potential of imperfect PM. Wang [26] added the imperfect PM concept to the basic model of [1]. His model considers an imperfect PM, a perfect PM to overhaul the system, and Corrective Maintenance (CM). More recently, Saidi-Mehrabad et al.[22] introduced a model which has the ability to implement perfect and imperfect PM activities in a multi-state system. All of these works have been considered in the context of integrated maintenance.

Some authors investigated the interaction between production, quality, and maintenance strategies in the context of HMRS. Gouiaa-Mtibaa et al.[8] considered a single machine subject to an increasing random failure rate, producing conforming and non-conforming items. Rework is adopted for non-conforming items in order to restore the products to their best quality. Polotski et al.[19] investigated the problem of optimizing joint production-maintenance policies in a failure-prone HMRS where returned products are assumed to be dissimilar in type and quality due to different collection and recovery procedures. Recently, Assid et al. [4] addressed a production planning and control problem in a reliable HMRS with varying quality conditions. Pongha et al.[15] analyzed a HMRS that degrades according to its production rate, affecting its availability and product quality.

Other researchers developed integrated models to study the link between production, maintenance and quality with outsourcing options. Haoues et al.[11] proposed an integrated approach to identifying the best outsourcing providers in a single-manufacturer-multiple-contractors relationship. Following the same logic of reasoning, Rivera-Gómez et al. [20] investigated the production, maintenance, quality and subcontracting strategies in a deteriorating manufacturing system. Recently, in the context of random subcontracting availability, Rivera-Gómez et al. [21] developed an integrated model where subcontracting was available at a higher cost to ensure demand satisfaction. On the other hand, the subcontractor was unreliable due to occasional disruptions caused by unexpected failures or because it was occupied serving other outsourcers.

Compared to the previous mentioned studies, the present paper aims to develop an integrated production-maintenance planning and quality control problem under outsourcing constraints in the context of HMRS. Unlike the first group of papers in the literature review, where they investigated separate manufacturing and remanufacturing processes, only a few papers looked at HMRS, which combines the two processes into one with shared resources.

Remanufacturing is economically more attractive than manufacturing a new product. In addition, remanufacturing is considered in our paper at both the in-house and outsourcing echelons. The outsourcing aspect is justified by the process-specific outsourcing instead of making up for the lack of capacity as in the majority of presented papers in the literature review (third group) of the HMRS context.

However, most analyzed papers have ignored the possibility that the HMRS would be unavailable due to breakdowns. As a result, a maintenance strategy is critical for keeping the system in optimal conditions. From this finding, we take into account that the capacity of the system is dependent on manufacturing, in-house remanufacturing and maintenance actions. These activities consume some of the production system's available capacity. In terms of reliability and maintenance aspects, we have adopted an imperfect PM strategy to reduce the risk of failures, and we carry out minimal repairs when the system fails.

Based on this critical analysis, the contributions in the body of literature attempt to cover some knowledge gaps in the literature by incorporating simultaneously system capacity dependency with manufacturing, in-house remanufacturing and maintenance actions, and imperfect PM strategy, returned products with different qualities, remanufacturing in both the in-house and outsourcing echelons with backlogging into one model in the context of HMRS. The main objective is to provide an answer to the question of which periods where manufacturing, remanufacturing, outsourcing and planned PM should take place in order to meet time-varying demand while minimizing the sum of overall costs over the planning horizon.

3. Problem description

The considered CLSC is composed of one manufacturer in a relationship with an outsourcing provider. The manufacturer produces and collects returned products. The outsourcing provider specializes in the remanufacturing of returned parts with particular characteristics and which require superior quality finishing operations that the manufacturer's system cannot remanufacture. Figure 1 shows the system being investigated.

In the forward process, the manufacturer purchases raw materials from an external supplier and processes them into new products. It operates a HMRS consisting of a capacitated single machine subject to random failures. The system uses both raw materials and returned products as part of its production process.

In the reverse process, the manufacturer collects returned products from the customers, sends them to the collection center, and then conducts an inspection process to evaluate the quality of the products. These latter are categorized as recoverable or unrecoverable. Non-recoverable products are sent to disposal, while recoverable products are classified as either in-house remanufactured or remanufactured by the subcontractor. Both of these remanufactured products are considered to be of the same quality as the newly manufactured ones.

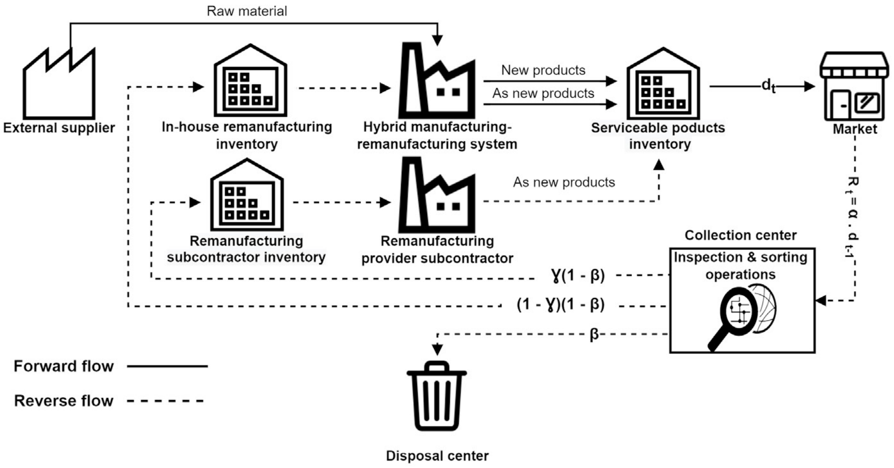

Fig. 1. Proposed CLSC network.

The basis of our problem is the capacitated single product lot-sizing problem with returns remanufacturing. The HMRS can produce one type of product during a given finite planning horizon defined by H, including T periods ($t \in T$) of the same length τ. The demand d_t is met at the end of each period t by new products, in-house remanufactured products, or outsourced remanufactured products. Backlogging is allowed. This means that the demand of the current period can be fulfilled in the next period with a supplementary cost. Also, the HMRS should be prepared for manufacturing or remanufacturing, so setup cost and time should be taken into account.

Throughout their lifespan, the HMRS undergo operations of maintenance to ensure their availability. In our policy, PM actions are assumed to be non-cyclical or cyclic imperfect PM, so that after each imperfect PM action, the machine's age is reduced and restored to an operating state between "As Bad As Old" (ABAO) and "As Good As New" (AGAN). Whenever the HMRS fails unexpectedly, a minimal repair is performed and the system is restored to its pre-failure working condition while its age remains the same. Furthermore, we assume that PM is performed at the beginning of periods, while at the beginning of the planning horizon, the system is not considered AGAN. Also, each PM or CM action carried out consumes some given amount of the system's nominal capacity.

4. Mathematical model

In this section, we will present the notations and our integrated model:

4.1. Sets

t	Index of period, where $t = \{1, 2, \ldots, T\}$.

4.2. Parameters

H	Finite planning horizon length.
T	Number of periods.
τ	Length of each period planning.
d_t	Demand of products in period t.
R_t	Number of returned products in period t, where : $R_t = \alpha d_{t-1}$.
W_t	Number of disposed products in period t, where : $W_t = \beta R_t$.
s_t^m	Setup cost for manufacturing a new product in period t.
s_t^r	Setup cost for in-house remanufacturing a returned product in period t.
c_t^m	Variable manufacturing cost for a new product in period t.
c_t^r	Variable in-house remanufacturing cost for a returned product in period t.
c_t^o	Unit outsourcing cost in period t.
c_t^w	Unit disposition cost in period t.
c_t^b	Unit backlogging cost in period t.
h_t^s	Holding cost of serviceable product in period t.
h_t^r	Holding cost of returned product for the in-house remanufacturing in period t.
h_t^o	Holding cost of returned product for the outsourcing remanufacturing in period t.
CMR	Minimal repair cost.
CPM	Preventive maintenance cost.
ρ^m	Unit manufacturing time.
ρ^r	Unit in-house remanufacturing time.
δ^m	Setup manufacturing time.
δ^r	Setup in-house remanufacturing time.
TMR	Corrective maintenance time.
TPM	Preventive maintenance time.
C_{max}^p	Nominal capacity of the HMRS (given in time units).
α	Fixed percentage of commercial returns.
β	Fixed percentage of disposed products.
γ	Fixed percentage of returned products for remanufacturing by outsourcing option.
θ	Machine age reduction factor, also called improvement factor.

4.3. Decision variables

Y_t^m	Binary variable for manufacturing in period t.
Y_t^r	Binary variable for in-house remanufacturing in period t.
X_t^m	Number of manufactured products in period t.
X_t^r	Number of in-house remanufactured products in period t.
X_t^o	Number of remanufactured products by subcontractor in period t.
X_t^b	Backlogging level of demand in period t.
I_t^s	Inventory level of serviceable products at the end of period t.
I_t^r	Inventory level of returned products for in-house remanufacturing at the end of period t.
I_t^o	Inventory level of returned products for remanufacturing by the subcontractor at the end of period t.
M_t	Binary variable for planned preventive maintenance at the beginning of period t.
Z_t	Binary variable for planned manufacturing and/or remanufacturing in period t.
a_t	Effective age of the machine at the beginning of period t.
EN_t	Mean number of failures of HMRS during period t.
$\overline{EN_t}$	Linearization variable, where: $\overline{EN_t} = EN_t Z_t$

4.4. Mathematical model

It is worth mentioning that our basic model is non-linear and we have linearized it. Hence, for the sake of brevity, we have presented only the linearized model.

$$\min \sum_{t\in T} (s_t^m Y_t^m + s_t^r Y_t^r + c_t^m X_t^m + c_t^r X_t^r + c_t^o X_t^o + c_t^b X_t^b + h_t^s I_t^s + h_t^r I_t^r + h_t^o I_t^o + c_t^w W_t + CPM \cdot M_t + CMR \cdot \overline{EN_t}) \tag{1}$$

s.t.

$$a_t = (1 - \theta \cdot M_t)\, a_{t-1} + \tau \cdot Z_t \qquad \forall t \in T \tag{2}$$

$$EN_t = \int_{a_t}^{a_t+\tau} \lambda(t)\, dt \qquad \forall t \in T \tag{3}$$

$$I_t^s - X_t^b = I_{t-1}^s + X_t^m + X_t^r + X_t^o - \left(d_t + X_{t-1}^b\right) \qquad \forall t \in T \tag{4}$$

$$I_t^r = (1-\gamma)(1-\beta) R_t + I_{t-1}^r - X_t^r \qquad \forall t \in T \tag{5}$$

$$I_t^o = \gamma (1-\beta) R_t + I_{t-1}^o - X_t^o \qquad \forall t \in T \tag{6}$$

$$\rho^m X_t^m + \rho^r X_t^r + \delta^m Y_t^m + \delta^r Y_t^r + TPM \cdot M_t + TMR \cdot \overline{EN_t} \le C_{max}^p \qquad \forall t \in T \tag{7}$$

$$X_t^m \le \left(\sum_{k\in T, k\ge t} d_k \right) Y_t^m \qquad \forall t \in T \tag{8}$$

$$X_t^r \le \left(\sum_{k\in T, k\ge t} d_k \right) Y_t^r \qquad \forall t \in T \tag{9}$$

$$X_t^b \le d_t \qquad \forall t \in T \tag{10}$$

$$Z_t \le Y_t^m + Y_t^r \qquad \forall t \in T \tag{11}$$

$$\overline{EN_t} \le EN_t \qquad \forall t \in T \tag{12}$$

$$\overline{EN_t} \le Maj \cdot Z_t \qquad \forall t \in T \tag{13}$$

$$\overline{EN_t} \ge EN_t + Maj\,(Z_t - 1) \qquad \forall t \in T \tag{14}$$

$$X_t^m, X_t^r, X_t^o, X_t^c, X_t^b, I_t^s, I_t^r, I_t^o \in \mathbb{Z}^+ \;\; and \;\; EN_t, \overline{EN_t} \in \mathbb{R}^+ \qquad \forall t \in T \tag{15}$$

$$Y_t^m, Y_t^r, M_t, Z_t \in \{0, 1\} \qquad \forall t \in T \tag{16}$$

$$I_0^s = I_0^r = I_0^o = X_0^b = d_0 = 0 \tag{17}$$

The objective function (1) minimizes the sum of setup, manufacturing, remanufacturing, outsourcing, backlogging, holding, disposal and maintenance costs over the entire planning horizon under time-varying demands and costs. Constraint (2) expresses the effective age function of the HMRS. The expected number of failures for the HMRS in a given time interval $(a_t, a_t + \tau]$ follows the non-homogeneous Poisson process and is expressed by constraint (3). Constraints (4), (5) and (6) are the inventory balance equations for serviceable products, returned products reserved for in-house remanufacturing and outsourced remanufacturing, respectively. Constraint (7) is the capacity restriction constraint for each period. It ensures that the total time needed to process all quantities manufactured and remanufactured is within the HMRS's available capacity, given its status in terms of the expected capacity loss during that period. Constraints (8) and (9) force $X_t^m = 0$ and $X_t^r = 0$ if $Y_t^m = 0$ and $Y_t^r = 0$, respectively, or free $X_t^m > 0$ and $X_t^r > 0$ if $Y_t^m = 1$ and $Y_t^r = 1$, the quantity $\left(\sum_{k\in T, k\ge t} d_k \right)$ is an upper bound of X_t^m and X_t^r. Constraint (10) expresses that backlogged demand must be less than the entire demand in that period. Constraint (11) ensures that all the variables Z_t are assigned the correct values whether each period has manufacturing and/or remanufacturing. The linearization of a multiplication of binary and continuous variables is represented by constraints (12), (13) and (14), where Maj is sufficiently large number. Constraint (15) ensures the integer non-negativity of the inventories, manufacturing, remanufacturing and outsourcing quantities. The binary values of the manufacturing, in-house remanufacturing and PM decisions are defined by constraint (16). Finally, constraint (17) determines the initial inventories, backlog and demand conditions.

4.5. Solution approach

The formulated mixed-integer programming problem is an extension of the classical capacitated lot-sizing problem, and it can be solved with any mixed-integer programming solver (such as the CPLEX solver using GAMS like in our case). Our approach entails assessing all of the PM's probable scenarios. The flowchart in Figure 2 illustrates this approach. The number of alternatives for PM solutions determines the maximum number of mixed-integer programs to be solved in order to determine the integrated production and maintenance plans.
Since each decision variable $M_t = (M_1, M_2, \ldots, M_T)$ can have only two values, 0 or 1, the maximum number of combinations as well as the number of mixed-integer programming problems to solve is $N = 2^T$.

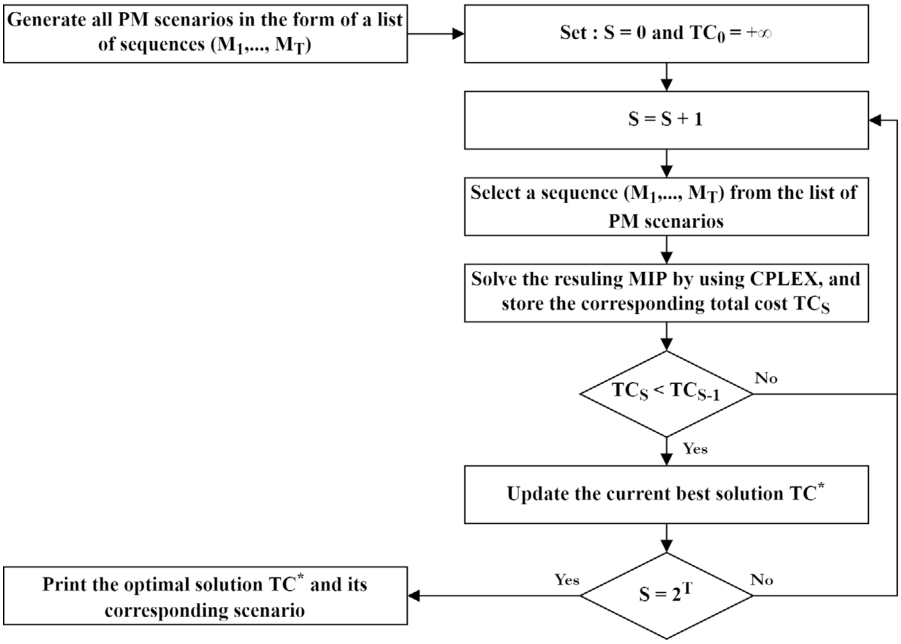

Fig. 2. Resolution procedure flowchart.

Our proposed integrated model considers the Capacitated Single-Item Lot-Sizing Problem (CSILSP) with remanufacturing, outsourcing and maintenance planning. In order to resolve the integrated problem, we must highlight that our procedure solves the CSILSP with remanufacturing $N = 2^T$ times. As a result, its complexity is influenced by the CSILSP with remanufacturing complexity (reduced proposed problem by not considering maintenance). In general, the CSILSP with remanufacturing is NP-hard [5]. So, in this paper, we considered only small-sized problems that can be solved with commercial solvers. To consider a larger number of periods, it is necessary to propose approaches based on meta-heuristics to solve them.

5. Numerical experiments

An experimental design based on the variation of several essential parameters that have a major influence on our results and conclusions has been implemented. The analysis takes four key factors into account: the number of periods, the demand pattern, the return percentage, and the cost structure. The design of the experiments is organized and inspired by [24], [1], [7], and [10].

5.1. Input data

Consider a planning horizon composed of T weeks, each having a maximum available capacity of $C^p_{max} = 50u.t.$. So that the demands are met at the end of each period, one product should be produced in lots. The demand patterns are generated based on the equation in [24]. The return ratio is set to 30%, 50%, or 70% as a percentage of the previous period's demand.
The cost structure is assumed to have the following assumptions: we consider a separate setup cost for each mode, where $s^m_t = 25u.c.$ and $s^r_t = 10u.c.$, the manufacturing cost is selected randomly from $[10, 20]$, from $[5, 10]$ for in-house remanufacturing cost, and the outsourced remanufacturing cost is selected randomly from $[15, 25]$. The holding cost is defined as $h_t = \omega\% \max\{c_t\}$, where ω is uniformly distributed between 5 and 20, and C_t will be replaced by c^m_t, c^r_t and c^o_t to determine h^s_t, h^r_t and h^o_t, respectively. The backlog cost is sampled randomly from the set of $\{25, 28\}$. To evaluate the HMRS capacity effectively, we assumed that the system required some setup times, with setup manufacturing time $\delta^m = 0.5u.t.$ and setup in-house remanufacturing time $\delta^r = 0.2u.t.$. Also, we consider that the unit manufacturing time $\rho^m = 1u.t.$ and the in-house remanufacturing time $\rho^r = 0.5u.t.$.

Now, if we consider the selected maintenance strategy, the cost of a PM action is set to $CPM = 28u.c.$, and the cost of a minimal repair action is given by $CMR = 35u.c.$. Let $TPM = 1u.t.$ and $TMR = 4.5u.t.$, the parameters defining the capacity lost when a PM action and unplanned CM actions are taken into account. $\theta = 0.5$ is the fixed percentage of age-function recovery under imperfect PM. Furthermore, we assume that the lifetime of the machine is distributed according to the Weibull distribution with two parameters. The shape parameter $\alpha = 2$ (α is set to 2 for linearization reasons) and the scale parameter $\beta = 100$.
This model is realized in GAMS v39.2.1 and solved with CPLEX and MATLAB on a desktop computer with an Intel Core i3 CPU at 3.07 GHz and 6 GB of RAM.

5.2. Results and discussions

The first group of tests of this experimental design consists of the variation of the number of periods. The average computational times are summarized in table 1.

Table 1. Average execution times (Seconds).

Instances	1	2	3	4	5	6	7	8	9	10	11	12
Number of periods	$T = 4$	$T = 5$	$T = 6$	$T = 7$	$T = 8$	$T = 9$	$T = 10$	$T = 11$	$T = 12$	$T = 13$	$T = 14$	$T = 15$
Execution time	1.0	2.4	5.4	12.0	24.8	56.0	107.8	240.0	591.7	1262.8	2375.1	5791.0

For the second group of tests, we consider a planning horizon of $T = 6$ weeks. d_t is the stationary demand of new products that should be met at the end of each period, where $d_t = \{51, 45, 47, 52, 48, 54\}$. To investigate the effects of cost variation on total and partial costs, 27 trials are performed where each trial is obtained by the variation of c^m_t, c^r_t and c^o_t, where $c^m_t = \{10, 15, 20\}$, respectively, for low, medium and high level costs. Similar levels hold for parameters $c^e_t = \{5, 7.5, 10\}$ and $c^o_t = \{15, 20, 25\}$. We note that the rest of the parameters are not changed during these trials. To discuss the results of the third class of tests, and for the sake of brevity, we will use the trial where low c^m_t, low c^r_t and medium c^o_t to discuss the results. Table 2 illustrates the optimal integrated plans for each return rate.

The results presented in Table 3 show the variation of return rates in relation to the percentage of representativeness of partial costs compared with the total cost. These results are for the ”LLM” test problem with 6 periods. For a fixed cost structure, we notice that each time the rate of return increases, the percentages of representativeness of the costs of manufacturing, backlogging and maintenance decreases. On the other hand, the percentages of representativeness of the costs of remanufacturing, outsourced remanufacturing, holding and disposing increase. From the assumptions

Table 2. Optimal integrated plans for the trial low c_t^m, low c_t^r and medium c_t^o.

	$t = 1$			$t = 2$			$t = 3$			$t = 4$			$t = 5$			$t = 6$		
R_t	0.3	0.5	0.7	0.3	0.5	0.7	0.3	0.5	0.7	0.3	0.5	0.7	0.3	0.5	0.7	0.3	0.5	0.7
X_t^m	45	45	45	37	29	41	39	27	0	43	36	26	42	42	38	29	28	28
X_t^r	0	0	0	8	13	0	7	12	34	0	11	16	0	0	9	24	26	26
X_t^o	0	0	0	6	9	12	5	8	11	5	8	11	6	3	0	1	0	0
X_t^b	6	6	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W_t	0	0	0	4	6	8	3	5	7	3	5	7	4	6	8	3	5	7
I_t^s	0	0	0	0	0	2	4	0	0	0	3	1	0	0	0	0	0	0
I_t^r	0	0	0	0	0	18	0	0	0	8	1	0	16	14	9	0	0	0
I_t^o	0	0	0	0	0	0	0	0	0	0	0	0	0	6	12	4	14	23

fixed during our formulation and experimental design (see the relevant sections), we conclude that the HMRS manager bases himself on a comparative advantage of the decision-making options and leans towards the plan (manufacturing-remanufacturing-maintenance) that is the most rational. In other words, the least expensive option that preserves the capacity of its system and consequently reduces the probability of failures and the associated costs. Also, this is explained by the use of returned products for in-house and outsourced remanufacturing; therefore, the PM plans are directly affected by the use of returned products for in-house remanufacturing. Hence, the number of planned PM actions is reduced.

Table 3. Variation of return rates in relation to the percentage of representativeness of partial and total costs.

R_t	MFC	RC	OC	BC	HC	DC	MC	TC	Maintenance plan
30%	62,31	5,61	11,46	3,74	1,20	6,36	9,33	100	(0,1,1,1,1,0)
50%	53,38	8,42	13,47	3,61	2,43	9,74	8,96	100	(0,0,1,1,1,0)
70%	44,30	10,81	15,81	3,49	4,02	12,90	8,67	100	(0,0,1,1,1,0)

6. Conclusion and future research directions

In this paper, we have studied the problem of integrated production and maintenance planning with different quality of returned products and outsourcing constraints in a CLSC setting. The manufacturer operates a HMRS composed of a capacitated single machine subject to random failures. The proposed maintenance strategy consists of performing a minimal repair when failure occurs. The CM actions restore the system to the operating status without altering the age of the machine. PM is also performed on the HMRS at predetermined periods to reduce the risk of fault occurrence. The PM actions are considered imperfect and reduce the age of the machine. We have developed an integrated control policy based on mixed integer programming, which aims simultaneously to determine the integrated maintenance planning in a hybrid manufacturing-remanufacturing context with an outsourcing option. The proposed strategy minimizes the total cost of the system over a finite planning horizon, including manufacturing, in-house remanufacturing, outsourced remanufacturing, maintenance, holding, backlogging, and disposal costs. To validate the proposed model, we implemented an iterative procedure using Matlab and the CPLEX solver of GAMS. Numerical experiments were presented to demonstrate the robustness and performance of the proposed policy. The managerial insights for the developed integrated strategy were conducted.

The experimental results show that our resolution approach works well on small and medium-sized problems. But, in large instances, it becomes difficult to solve these problems. Furthermore, the multi-product context is an interesting extension, but such considerations usually involve other more complicated issues that are not addressed in the current research. This idea is under development, where an approach based on meta-heuristics will be implemented to solve large-sized problems.

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