Hybrid Remanufacturing/Manufacturing Systems: secondary markets issues and opportunities

M. GALLO, L. GUERRA, G. GUIZZI
Department of Materials Engineering and Operations Management
University of Naples "Federico II"
P.le Tecchio – 80125 Napoli
ITALY
mose.gallo@unina.it luigi.guerra@unina.it g.guizzi@unina.it http://www.impianti.unina.it

Abstract: In this paper secondary markets opportunities for hybrid remanufacturing/manufacturing systems will be analyzed. Recovering options allow increasing product's inherent value recovery rate and it have been experimented by many manufacturers for several years. Particularly, the *remanufacturing* has been receiving great attention from many OEMs. In this case, the joint presence of *high quality* returns and demand for such products on secondary markets (e.g. *emerging markets*), makes the management deciding about allocating these units on these secondary markets rather than remanufacturing them and supplying the primary market. To gain insight into such a system a simulation model has been developed by means of *Arena* and a statistical analysis of data obtained from some experimental campaigns has been carried out. In this way, the factors that mainly impact on system performance and the operating conditions in which selling on the secondary market is more profitable will be identified.

Key-Words: Strategic analysis, Quality uncertainty, Remanufacturing, Secondary markets, Simulation.

1 Introduction

The aim of product recovery is to retrieve a product's inherent value when the product no longer fulfils the user's desired needs. Product recovery involves concepts like reuse, remanufacturing and recycling. This article only investigates remanufacturing, which is defined by Fleischmann et al. as a process of bringing the used products back to `as new' condition by performing the necessary operations such as disassembly, overhaul and replacement [3].

Remanufacturing as a product recovery operation is extensive and includes product inspection, disassembly, cleaning and identification of parts, parts recovery, product re-assembly and testing to ensure it meets the desired standards.

The order and the purpose of the different operations are not standardized, but are rather dependent on the individual remanufacturing cases and the needs for recovery of specific components [17].

Remanufacturing has proved to be economically and environmentally better than ordering new products. The concept of remanufacturing has spread during the latest decades through sectors such as electrical equipments, toner cartridges, home appliances, machinery, cellular phones and many others.

Even if many producers specialize in remanufacturing products, some original equipment manufacturers (OEM) may choose to combine manufacturing and remanufacturing activities together. In this latter case an OEM have to coordinate manufacturing with remanufacturing operations.

V. R. Daniel and Guide Jr. cited seven major characteristics of recoverable manufacturing systems that definitely make hard the production planning and control activities [5].

Large variations in the quality of returns is a major factor for uncertainties in the remanufacturing processing times and the recovery rates of the process. Consequently balancing demands with returns becomes quite complicated [2].

Large variations in the quality of returns is a major factor for uncertainties in the remanufacturing processing times and the recovery rates of the process. Consequently balancing demands with returns becomes a complicated problem [2, 5].

To manage this variability, one of the first operations of any remanufacturing process is the inspection/test of returns from the primary market. This activity aims to assign a quality level (high, medium, low) to returns on the basis of their functional and aesthetics.

Besides reducing the operation costs, the classification of returns can also create new market opportunities: higher quality products could be sold "*as is*" on secondary markets or after some minor repairs.

The limited availability of production capacity and cores, and the presence of two markets necessitate finding the optimal mix of sales in order to maximise profits.

This choice is influenced by several factors.

Firstly the characteristics of the return flow must be considered both in terms of primary market demand share and mix quality level.

In addition mark-up from sales in both markets must be taken into account. In the following analysis it will be assumed that new and remanufactured products can be sold in the primary market at the same price (P) meanwhile high quality returns can be directly sold in some secondary market at a lower price (p). It should be noticed that the margin resulting from remanufactured products is not fixed as for new products but it depends on their quality level: a high quality core has little remanufacturing costs and thus it will result in higher mark-up.

Also service level delivered on the primary market is an important factor. Due to the limited availability of cores and production capacity, the primary and secondary market demand cannot completely be met in several conditions. As the primary market is the core business for the company and as it's more demanding about delivery delays and lost sales, we have to assess the primary market service level when choosing among different operational alternatives.

Another important factor influencing the mix of sales is the average global capacity utilization rate. This design parameter, in fact, influences the available capacity at the various work centers.

The purpose of this paper is to identify, in different scenarios, the significant factors that affect the performance (i.e. profit) of a hybrid remanufacturing/manufacturing system when supplying a secondary market. Besides, break-even price in the secondary market and significant factors for such parameter are evaluated in each scenarios.

This paper is further organized as follows. In Section 2 the relevant literature on hybrid systems performance evaluation, quality of returned products and influence of secondary markets in a remanufacturing environment is reviewed. In Section 3 the model and its theoretical foundations are discussed. In Section 4, simulation results are presented. Section 5 reports our findings on secondary market *break-even price*. In Section 6 some issues an OEM have to cope with when managing a secondary market are discussed. The paper is concluded in Section 7.

2 Literature review

Considered research flows are mainly related to:

- performance analysis of Hybrid Remanufacturing/Manufacturing Systems (HRMS) with returns classification;
- influence of secondary markets in remanufacturing settings.

As regards the first point, a thorough literature review can be found in [2]. Moreover, in such paper, the authors developed a multi stage inventory control model for a hybrid production system to assess the profitability of quality based returns classification. According to this study, a way to cope with the quality variability of returns is to perform some cores classification before the remanufacturing process is carried out. This classification allows, in some situations, significant savings on operating costs per unit of time.

In particular, the analysis made by Behret and Korugan [2] denotes that the quality based classification leads to significant savings in case of high rates of returned products. In addition, the paper indicates that the savings achieved by the classification increase if:

- the arrival rate of different quality returns became closer;
- the difference among material recovery rates increases;
- the difference among costs of returned product classes increases;
- the variance of remanufacturing times increases.

The classification of the cores enables hybrid systems to mainly produce high quality products and to dispose the low quality ones so to minimize the total cost.

Returned products quality issues and remanufacturing management were also addressed in [1], where a model based on continuous time markovian chains using a pull disposing strategy is built and remanufacturing lead time referring to returned product quality and disposal costs are calculated.

The development of secondary markets, particularly for electrical and electronic equipment, is strongly linked to the growth of their demand in developing countries [25]. One of the main companies operating in this field is the *American ReCellular Inc.*. This

company purchases used mobile phones on the US market and then resells them in South America or Africa [18].
The growing number of remanufacturing companies is justified by the fact that products who no longer have demand in the primary market still have appeal in the secondary one. For mobile phones, for example, secondary markets gets less than 1% of new products sales [15]. Another kind of secondary market deals with the components. This market is still in its first phase of development. An example could be that of computer chips, which could be alternatively used in equipment like toys [4].
Secondary market issues have been addressed in many different ways in literature. Some studies addressed the problem from a logistical point of view. S.K Srivastava and R.K. Srvivastava considered issues on returned products flows quantifying and managing in several secondary markets, for different products types [24]. S.K. Srivastava analyzed design issues of a reverse logistics network serving the secondary market by determining the number and location of returned products collection points [25]. Souza et al. studied the effects on profit by reducing return time as a result of logistics system improvements [23]. Bhattacharya et al. analyzed the impact of the remanufacturing option on core acquisition process for companies operating in secondary markets [18]. Mitra analyzed different selling price policies for remanufactured or refurbished products in order to maximize profit [12]. Heese et al. and Mont et al. evaluated the potential benefits that an OEM could achieve controlling the secondary market [6, 14]. Oraioupoulos et al. analyzed the opportunity for an OEM operating in the IT sector, to eliminate or not their secondary market over-taxing licenses reuse [16].
Aforesaid works focused on several aspects of secondary markets, but they didn't consider its impact on production systems operation and performance. Unlike the others, Souza et al. analyzed production planning and control problems for companies operating on two different markets (remanufactured products market and "*as is*" sold products market) [10].

3 Logical model, analytical model and theoretical foundations

In this paper, a specific model based on the generic hybrid remanufacturing manufacturing shop depicted in Fig. 1 will be proposed.
We will refer to an OEM that remanufactures products. Specifically, manufacturing and remanufacturing operations take place in the same plant. This resources sharing makes a more complex question deciding on the optimal mix of new and remanufactured products, especially with constrained production capacity and when the service level is a critical factor [22].

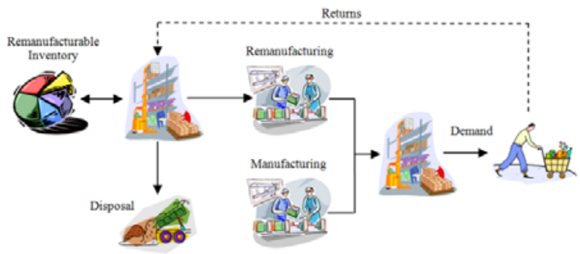

Fig. 1 - A schematic representation of a hybrid remanufacturing/manufacturing system with stocking points for serviceable and remanufacturable products (HRMS).

It will be assumed that remanufactured products are perceived "*as good as new*" by consumers on the primary market.
Even if this assumption is not always truthful, because consumers may be willing to buy remanufactured products at a lower price, it is fairly adopted in remanufacturing literature [19, 9]. Consumers willing to pay for remanufactured products strictly depends on the trust they put in the remanufacturing subject: the OEM, third company licensed by the OEM, independent company. Probably, the OEM could obtain a greater confidence as he has technical information, technology and expertise necessary for an effective remanufacturing [11].
The multi stage inventory control model considered is similar to that proposed by Behret and Korugan in [2], if it is excepted the presence of secondary markets for the high quality returns (Fig. 2).
The operation of the considered HRMS firstly requires the returns flow classification into three classes with different quality levels. High quality returns can be sold "*as is*" on a secondary market at a lower price (p).
As quality and price of remanufactured and new products are different from those of products sold "*as is*", the two markets may be considered independent [12].
Demand and returns flow are modeled by two independent Poisson distributions with parameter γ and $r \cdot \gamma$, with $0 < r < 1$ [27].

We considered a product in the maturity phase of its life cycle. The secondary market demand is a share of the primary market one.

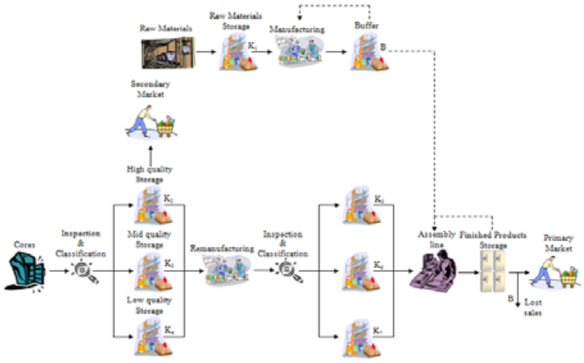

Fig. 2 - Multi stage inventory control model with a secondary market

Because of capacity constraints, the manufacturing stage cannot fully meet the primary market demand in each possible scenario.

The profitability of serving a secondary market with some high-quality cores has been assessed comparing the performances (i.e. profit) obtained supplying the secondary market with different amounts of high quality cores, with that obtained when just the primary market is supplied.

For the notation and the methodology for estimating manufacturing and remanufacturing processing time and holding costs you can refer to [2].

The profit function with sales on both markets is as follows:

$$\Pi_{msu} = \lim_{T \to \infty} \frac{1}{T} E\left(\Pi_{ms}\right) = \left(P \times N_s\right) + \left(p \times N_{s2}\right) - \left[\begin{array}{l} \left(C_{RW} \times RW\right) + \left(C_R \times R\right) + \sum_{i=1}^{3}\left(CP_{r_i} \times \pi_{r_i} \times v_{r_i}\right) \\ + \left(CP_M \times \pi_m \times v_m\right) + \left(CP_a \times \pi_a \times v_a\right) + \\ + \sum_{i=1}^{3}\left(CDO_i \times NDO_i\right) + \sum_{i=1}^{4}\left(CD_j \times ND_j\right) + \\ + \sum_{i=1}^{8}\left(CH_j \times NQ_j\right) + \\ + \left(CH_{fps} \times NQ_{fps}\right) + \left(C_b \times N_b\right) \end{array}\right] \quad (1)$$

where:

- N_s is the expected sale rate on the primary market;
- N_{s2} is the expected sale rate on the secondary market;
- P is the price on the primary market;
- p is the price on the secondary market.

Equation (1) represents the total profit per unit of time, estimated in stationary conditions.

The objective function depends on the capacities of the buffers K, B, K1, K2, K3, K4, B5, and on the backorder capacity B [2]. These variables, in fact, affect both revenues and operating costs.

The profit function that does not include sales on the secondary market is similar to Equation (1) with the exception of the revenues from the secondary market.

4 Model analysis and results

4.1 Solution methodology, control parameters and scenarios

It may be hard finding any analytical solution to the mentioned problem. Here a simulation based approach is proposed. Particularly, in this paper a simulation model of the problem has been built with *Arena 8.0* and the objective function has been maximized by means of the *OptQuest* tool in a metaheuristic way.

The simulation results were compared in several scenarios corresponding to various secondary market sizes: 5, 15 and 20% of the primary market demand. The maximum size of the secondary market is similar to that obtained by Souza et al. (16% - 22%) [10], higher values would affect system performance in most of considered cases.

The selling price on the secondary market (p) is set at 70% of the price of the product (remanufactured or new) on the primary market [10]. This value is the highest possible price on the secondary market.

Secondary market profitability is related to return flow and system's features (Table 1).

Table 1 – System parameters

Variables	Levels		
Return rate (r)	0,7	0,8	0,9
Return mix (K_i)			
K_1 K_2 K_3	0.33 0.34 0.33	0.5 0.3 0.2	0.8 0.1 0.1
Average global capacity utilization rate (ρ_{avg})	0,8	0,9	

As regards the return flow, return rate and return mix are considered. These factors are closely related to the reverse logistics system adopted. Considered return rate values are typical of the maturity phase of products life cycle. Since our aim is to assess the profitability of using some high quality returns to meet the secondary market demand, the percentage

of high quality returns in the return mix will be at least 33%.
As regards the system's features, we considered the average capacity utilization rate as reference parameter.
The average capacity utilization rate is a design parameter that depends on:

- possible developments of the primary market;
- additional uncertain factors that can slow down the system;
- capital investments issues.

It is likely that this design choice was made regardless the opportunity of serving some secondary markets, as this chance usually occurs only at the maturity phase of the product life cycle.
The cost ratios are based on data grounded in real remanufacturing environments from the existing literature (Table 2).

Table 2 – Cost ratios

<table>
<tr><th colspan="5">Costs parameters</th></tr>
<tr><td>Raw material and Manufacturing costs</td><td colspan="2">CRW = 0.1</td><td colspan="2">CPm = 10</td></tr>
<tr><td>Remanufacturing costs</td><td>$CPr_1 = 1$</td><td colspan="2">$CPr_2 = 3$</td><td>$CPr_3 = 5$</td></tr>
<tr><td>Assembly costs</td><td colspan="4">CPa = 5</td></tr>
<tr><td>Holding cost rate</td><td colspan="2">h = 0.01</td><td colspan="2">$\alpha = 1$</td></tr>
<tr><td>Disposal costs</td><td>$CD_1 = -0.1$</td><td colspan="3">$CD_1 = CD_2 = CD_3 = 1$
$CDO_1 = CDO_2 = CDO_3 = 1$</td></tr>
<tr><td>Selling price on the primary market (P)</td><td colspan="4">50</td></tr>
</table>

A full factorial experimental design (3^2*2=18 experiments) was used.

Table 3 – Full factorial design

<table>
<tr><th>N°</th><th colspan="3">Returns mix</th><th>r</th><th>ρ</th></tr>
<tr><td>1</td><td>33</td><td>34</td><td>33</td><td>0,7</td><td>90%</td></tr>
<tr><td>2</td><td>33</td><td>34</td><td>33</td><td>0,8</td><td>90%</td></tr>
<tr><td>3</td><td>33</td><td>34</td><td>33</td><td>0,9</td><td>90%</td></tr>
<tr><td>4</td><td>50</td><td>30</td><td>20</td><td>0,7</td><td>90%</td></tr>
<tr><td>5</td><td>50</td><td>30</td><td>20</td><td>0,8</td><td>90%</td></tr>
<tr><td>6</td><td>50</td><td>30</td><td>20</td><td>0,9</td><td>90%</td></tr>
<tr><td>7</td><td>80</td><td>10</td><td>10</td><td>0,7</td><td>90%</td></tr>
<tr><td>8</td><td>80</td><td>10</td><td>10</td><td>0,8</td><td>90%</td></tr>
<tr><td>9</td><td>80</td><td>10</td><td>10</td><td>0,9</td><td>90%</td></tr>
<tr><td>10</td><td>33</td><td>34</td><td>33</td><td>0,7</td><td>80%</td></tr>
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<tr><td>13</td><td>50</td><td>30</td><td>20</td><td>0,7</td><td>80%</td></tr>
<tr><td>14</td><td>50</td><td>30</td><td>20</td><td>0,8</td><td>80%</td></tr>
<tr><td>15</td><td>50</td><td>30</td><td>20</td><td>0,9</td><td>80%</td></tr>
<tr><td>16</td><td>80</td><td>10</td><td>10</td><td>0,7</td><td>80%</td></tr>
<tr><td>17</td><td>80</td><td>10</td><td>10</td><td>0,8</td><td>80%</td></tr>
<tr><td>18</td><td>80</td><td>10</td><td>10</td><td>0,9</td><td>80%</td></tr>
</table>

Each experiment (Table 3) was repeated for all considered scenarios assuming no secondary market situation as the fourth scenario (3^2*2*4=72 experiments).

4.2 Simulation results

For each experiment we estimated the percentage difference between the profit obtained when the secondary market is supplied with a certain amount of high quality cores, with that obtained when just the primary market is supplied ($\Delta\pi$ %).
Profit differences were derived assuming the maximum selling price value on the secondary market. The significance of these differences was evaluated through a *paired-t confidence interval* approach. This test was performed by means of the statistical tool built in Arena, the *Output Analyzer*, setting the significance level $\alpha = 0.05$ [8]. Values marked with *** are not significant (Table 4).
Statistical significance of the considered factors was assessed by ANOVA analysis using *Design Expert 7.0* (Fig. 2). All considered factors were significant (Fig. 3, Fig. 4, Fig. 5, Fig. 6).
Evaluating the effects of each factor:

- improving the return mix quality led up to 5,636% increase in profit;
- improving the return rate led up to 5,155% increase in profit;
- improving the secondary market size led up to 4,284% increase in profit;
- decreasing average capacity utilization rate led up to 4,142% increase in profit.

The first two factors influence the number of products that can be used for the primary market.

Table 4 – Profit percentage differences with respect to no secondary market case

	Market 5%	Market 10%	Market 20%
1	-0,697%	-1,710%	-3,728%
2	***0,000%	-0,756%	-2,361%
3	2,136%	2,516%	1,095%
4	***0,028%	-0,568%	-2,437%
5	2,399%	3,204%	2,154%
6	2,422%	5,098%	6,664%
7	2,087%	3,638%	3,155%
8	2,563%	4,911%	8,244%
9	2,942%	5,866%	11,251%
10	***-0,161%	-0,942%	-2,895%
11	2,213%	2,488%	0,947%
12	2,835%	5,300%	6,043%
13	2,129%	2,584%	1,094%
14	2,851%	5,405%	6,720%
15	2,926%	5,535%	10,515%
16	2,744%	5,360%	7,487%
17	2,891%	5,828%	10,901%
18	3,036%	6,281%	12,263%

Response	1	Diff. profitto				
ANOVA for selected factorial model						
Analysis of variance table [Classical sum of squares - Type II]						
Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	663.83	25	26.55	33.20	< 0.0001	significant
A-Returns Rate	162.44	2	81.22	101.54	< 0.0001	
B- Returns mix	233.33	2	116.67	145.85	< 0.0001	
C- Average Capacity Util. Rate	53.30	1	53.30	66.63	< 0.0001	
D- Secondary market size	55.27	2	27.64	34.55	< 0.0001	
AB	10.50	4	2.62	3.28	0.0252	
AC	0.34	2	0.17	0.21	0.8101	
AD	56.53	4	14.13	17.67	< 0.0001	
BC	2.75	2	1.38	1.72	0.1972	
BD	77.74	4	19.44	24.30	< 0.0001	
CD	11.61	2	5.80	7.25	0.0029	
Residual	22.40	28	0.80			
Cor Total	686.22	53				

Fig. 3 – ANOVA analysis results

The first factor, however, has a deeper impact on profit difference being quite different the recovery rate for remanufactured products of various quality level (in our case 90%, 60% and 30% respectively for high, medium and low quality products).

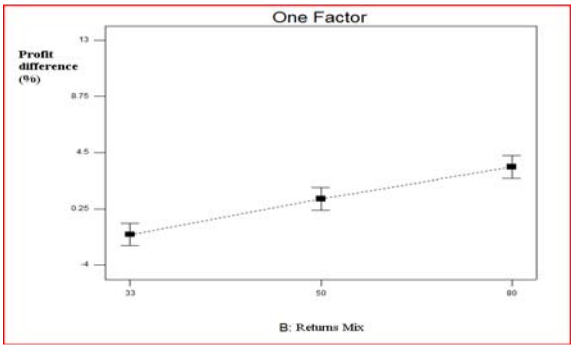

Fig. 4 – Profit percentage difference vs. return mix

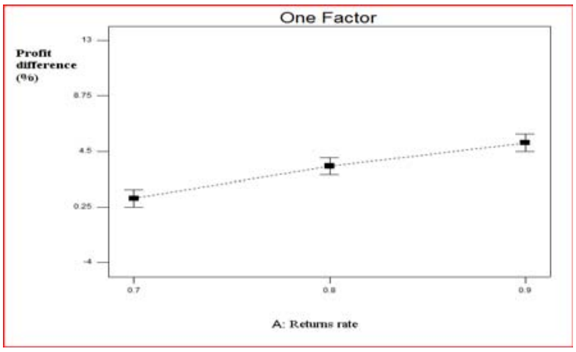

Fig. 5 – Profit percentage difference vs. return rate

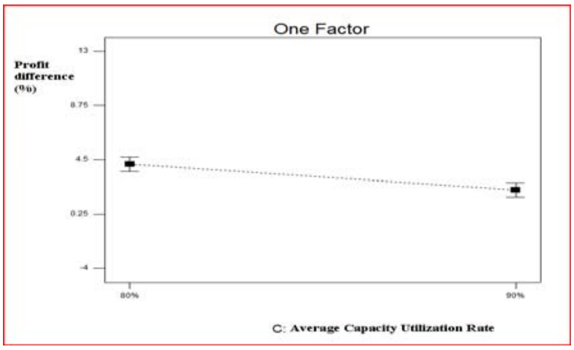

Fig. 6 – Profit percentage difference vs. average capacity utilization rate

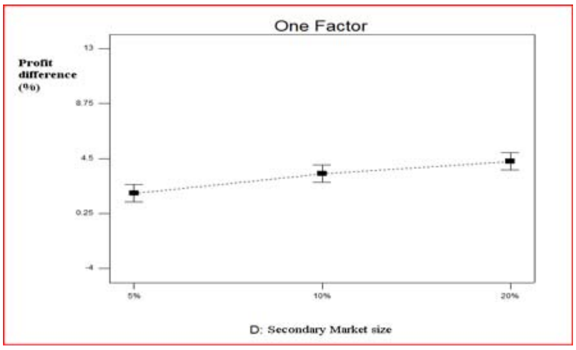

Fig. 7 – Profit percentage difference vs. secondary market size

When the secondary market size increases, also the profit difference increases because of the higher revenues on the secondary market. This, however, cuts primary market profits (newly manufactured products are less profitably if compared with remanufactured ones). Therefore, there are some situations in which the increasing profit on the secondary market doesn't compensate for its decreasing on the primary one, so this factor is less significant than the others.

Low values for the average capacity utilization rate make profitable supplying secondary markets: if the system works faster, it can deliver a higher customer service level on the primary market.

As regards the interaction effect between return rate and secondary market size (Fig. 8), the lower the return rate values, the smaller the supplied secondary market demand. As returns rate grows, larger secondary market demand should be supplied. The same goes for the interaction between returns mix and secondary market size (Fig. 9).

We, also, evaluated the service level delivered by the system on the primary market as secondary market size grows up (Table 5).

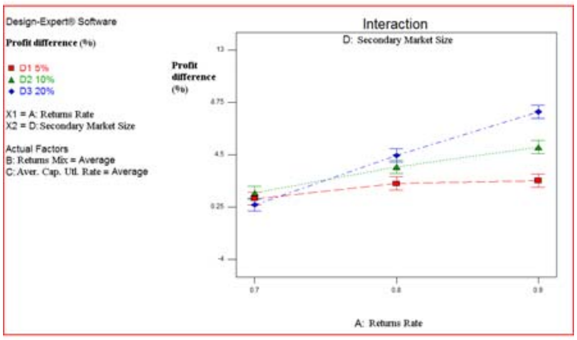

Fig. 8 – Interaction effect between return rate and secondary market size

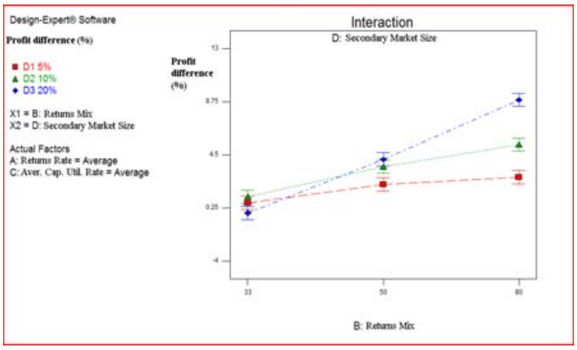

Fig. 9 – Interaction effect between return mix and secondary market size

Table 5 – Service Level values for various secondary market sizes

	Market 0%	Market 5%	Market 10%	Market 20%
1	92,0%	87,6%	83,2%	74,1%
2	97,3%	93,5%	88,9%	80,3%
3	99,2%	98,3%	94,6%	86,1%
4	98,0%	93,8%	89,2%	80,5%
5	99,5%	98,9%	96,1%	87,4%
6	99,8%	99,6%	99,5%	94,2%
7	99,5%	99,2%	98,4%	88,8%
8	99,8%	99,7%	99,6%	96,7%
9	99,9%	99,7%	99,6%	96,9%
10	97,8%	94,0%	89,4%	80,3%
11	99,6%	98,9%	95,2%	86,5%
12	99,9%	99,8%	99,2%	92,5%
13	99,7%	98,8%	95,5%	87,2%
14	99,8%	99,5%	99,4%	93,7%
15	99,9%	99,9%	99,6%	99,0%
16	99,9%	99,8%	99,6%	95,1%
17	99,9%	99,9%	99,9%	99,5%
18	99,9%	99,9%	99,9%	99,8%

In most cases, configurations with a service level lower than 90% make lower average profits if compared with the corresponding no secondary market configuration. In some cases, however, sales on the secondary market increase profit but drive down service level values (below 90%): in such cases it is probably advisable not to fully satisfy the secondary market because of a loss of public image in the long term.
Table 5 shows that the service level increases as quality and quantity of returns increase. Moreover, in most cases, it decreases as the secondary market size increases. Such decreasing is faster when return flow is poor, either from a quantitative or a qualitative point of view, and the average capacity utilization rate is high: just when the return rate is high, the mix quality is “good” and the average capacity utilization rate is low (experiment 17 and experiment 18) the secondary market size doesn’t impact system performance.

5 Price variation effects

Profit percentage differences in Table 3 have been calculated assuming a particular selling price on the secondary market. It is useful, therefore, comparing considered configurations also with respect to the *break-even price*.
Table 6 shows break-even price values (p_r) for the various configurations. The break-even price is significantly influenced by previously considered factors (Fig. 10, Fig. 11, Fig. 12, Fig. 13, Fig. 14).

Table 6 – Break-even price values

	Market 5%	Market 10%	Market 20%
1	38,528	39,327	39,717
2	35,000	37,026	38,164
3	23,212	29,106	33,488
4	34,838	36,629	38,490
5	20,768	25,498	31,805
6	20,252	19,480	24,840
7	21,754	23,455	29,993
8	18,182	18,890	21,478
9	15,168	15,229	16,040
10	35,928	37,713	39,168
11	22,382	27,652	33,600
12	18,052	19,160	24,590
13	21,722	26,942	33,294
14	16,904	17,851	24,339
15	16,094	17,120	18,015
16	16,556	16,991	22,422
17	15,118	14,960	16,259
18	13,626	12,894	13,422

In particular their effect on break-even price is similar to that on profit with the exception of the secondary market size: as the secondary market size increases, also the break-even price increases.
As the return rate or the return mix quality increase, the break-even price decreases: a larger number of remanufacturable products allows a lower price on the secondary market.
In this case, however, the secondary market size has a negative effect on the break-even price. In fact, because of the increased demand on the secondary market, profit on the primary market decrease and the increased number of sales on the secondary market cannot compensate for the poor results obtained on the primary one Therefore, as the secondary market size increases, the secondary market profits increase too but the prices range is tighter.
With regard to the average capacity utilization rate low values may be preferred: an increase in production capacity availability allows to deliver an higher service level on the primary market and a lower price on the secondary one.

Response 1 Breakeven Price

ANOVA for selected factorial model

Analysis of variance table [Classical sum of squares - Type II]

Source	Sum of	df	Mean Square	F Value	p-value Prob > F	
Model	3733.24	25	149.33	22.34	< 0.0001	significant
A- Return Rate	1161.55	2	580.78	86.89	< 0.0001	
B- Returns Mix	1727.65	2	863.82	129.24	< 0.0001	
C- Avg. Cap. Util. Rate	436.81	1	436.81	65.35	< 0.0001	
D- Secondary Market size	260.01	2	130.00	19.45	< 0.0001	
AB	94.60	4	23.65	3.54	0.0186	
AC	5.42	2	2.71	0.41	0.6703	
AD	7.92	4	1.98	0.30	0.8780	
BC	15.33	2	7.67	1.15	0.3321	
BD	23.40	4	5.85	0.88	0.4912	
CD	0.55	2	0.28	0.041	0.9596	
Residual	187.15	28	6.68			
Cor Total	3920.39	53				

Fig. 10 – Break-even price, ANOVA analysis

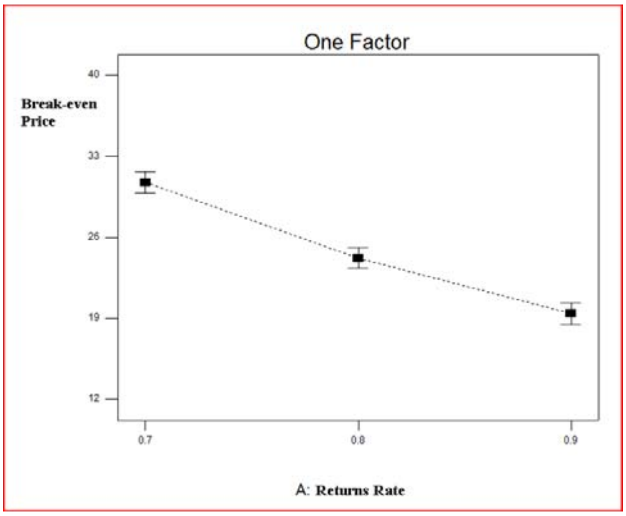

Fig. 11 – Break-even price vs. return rate

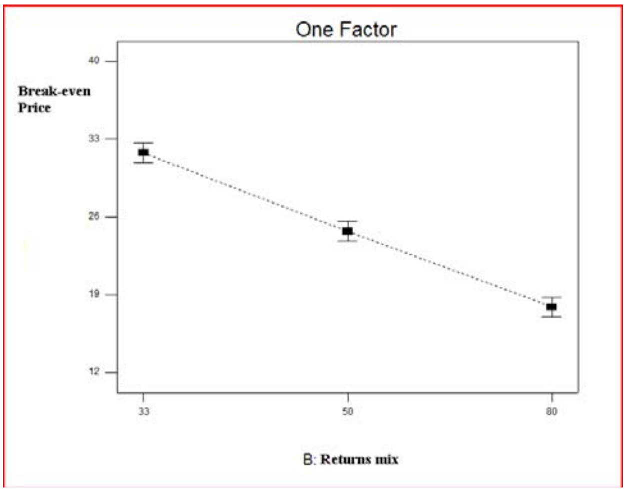

Fig. 12 – Break-even price vs. return mix

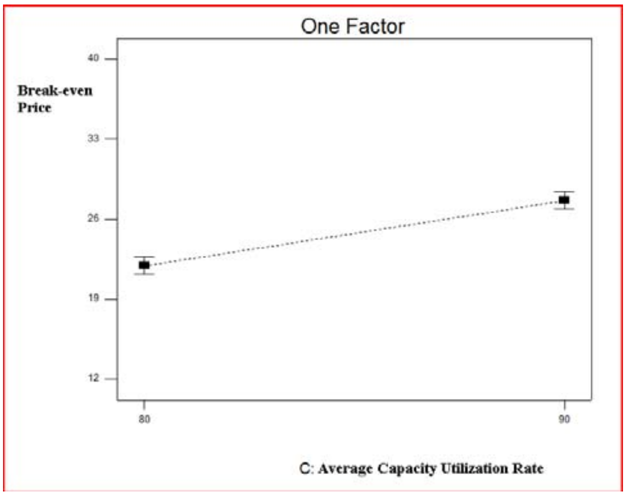

Fig. 13 – Break-even price vs average capacity utilization rate

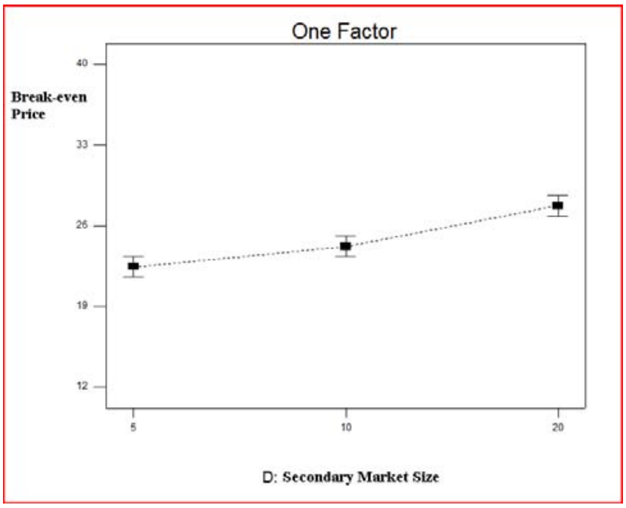

Fig. 14 – Break-even price vs secondary market size

Return rate and return mix affect the break-even price in a similar way so, if both increase, the benefits on the break-even price are amplified (Fig. 15).

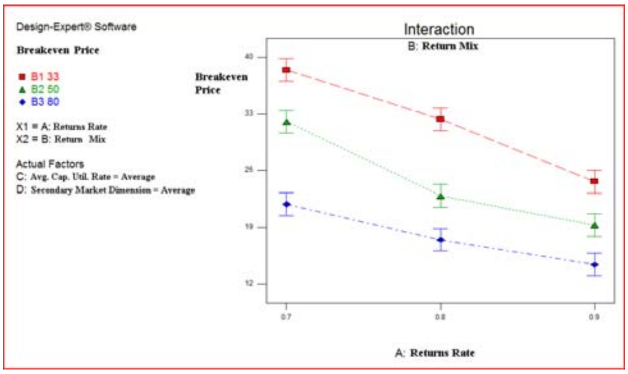

Fig. 15 – Return rate and return mix quality effects on breakeven price

6 Secondary market management issues

OEMs have to manage above mentioned factors to decide about selling opportunities on secondary markets. In the following the industrial best practices to cope with these issues will be addressed.

Reducing the average capacity utilization rate allows to produce more units to compensate for remanufacturing process output decreasing due to the high quality cores supplying the secondary market. In some cases, however, it is not convenient to increase the number of newly manufactured products. It could be the case of the *downward substitution*: some companies would provide customers that are asking for remanufactured products, with new products (generally sold at a higher price) when remanufactured ones are not available. This happens, for example, in the automotive field [10].

Return rate is strongly linked to the advertised incentives for the customers who give back the used products. The *trade-in* system is widely used: it consists in appraising the residual value of the product which is then converted into a discount on the new product. The residual value appraising depends on the model and it does not take care about product conditions. Many other companies arrange *buy-back programs*. For example HP buys used equipment offering various options to the customers including *revenues sharing* and *fixed price* (depending on the model). In particular, the *revenues sharing* system allows to retrieve products with a higher residual value. Other options are *refinancing*, *leasing* and *acquisition prices*.

Returns management policies differ from case to case and aim both to remanufacturing objectives and to attract new customers. Therefore, there's little to say about their effectiveness in remanufacturing contexts [11]. Often such policies aim to preserve customers to buy products from other companies, to reset the secondary market for an old technology while introducing a new technology or to increase purchasing frequency.

Returned products condition is a critical factor too. In case of poor quality the feasible options may be recycling, disposal or retrieval of components to be used as spare parts or to be directly sold on the secondary markets. When a particular quality threshold is exceeded, then remanufacturing is the right option. Also, if high quality returns occur, the product can be sold "*as is*" or after some minor repairs. Quality, however, is hardly predictable as it closely depends on product use and its operational conditions. So it is difficult to obtain high quality return mix. However, maintenance contracts (economically feasible only for expensive products such as industrial machinery) and robust design can improve the average mix quality [26].

Some analysis showed that the return mix quality is the factor that more raises profits by increasing the number of sales on the secondary market. In fact, if a high percentage of high quality returned products occurs, even if the return rate is poor and the capacity utilization rate of the system is high, then supplying a secondary market is a profitable option. So, returned products quality is critical to selling opportunities on secondary markets for an OEM. Currently, OEMs not always have return flows characterized by a sufficient percentage of products for which "*as is*" sale is possible.

For independent *third party* companies involved in remanufacturing, the situation is quite different.

For these companies, in fact, returns availability is high and returns quality can be monitored by acquisition price. These companies, for a certain product category, remanufacture many models of various OEMs (for some products, such as mobile phones, OEMs are not currently involved in remanufacturing) and they buy only the best returned products. For example when remanufacturing mobile phones, companies buy cores from many sources, including third party companies engaged in collecting used products and telephone companies. Third party companies are often charity foundations that directly collect mobiles from final customers while telephone companies collect products from their customers when their service contract is expired. Both sources offer different lots, characterized by different quality levels with different purchasing prices [6].

So, for a third party engaged in remanufacturing, the secondary market is always profitable. Instead, it could be less attractive for OEMs because of the low percentage of returned products that can be sold "*as is*".

A further difficulty for OEMs is to sell remanufactured products and new products at the same price. Consumers behavior have to be considered in this case: remanufactured products quality is considered poor if compared with new ones. Labels and quality certifications could help to make consumers more aware of remanufactured products quality. For this purpose new and remanufactured products should be sold with the same guarantee or environmental concerns of remanufactured products should be stressed.

Moreover some OEMs are changing the way of conducting their business to better manage and control the market, preventing the effects of a poor quality delivered by third parties: they no longer sell products but services. By means of *leasing contracts*, products are automatically replaced after a fixed period; returned products may be refurbished, remanufactured or sold "*as is*". The customer, not being the owner of the product, doesn't care about product origin. In this way OEMs can have a greater control over the return process and over the secondary market too. This policy is widely adopted in the electrical and electronic equipments field (*Xerox*) and now it is spreading in other different fields. An example is a Swedish firm leader in producing baby strollers: following the above mentioned approach she increased profits, took control of the "second hand" market and improved her public environmental image [13].

As regards mobile phones field, till nowadays, OEMs preferred not to directly engage with used products recovery but things are going to change. Market evolution, especially in emerging countries, stricter environmental regulations, customers expectations and third parties profits in recovering their products, are forcing OEMs towards more active roles. As proof it can be mentioned the *SouthernLINC* case: each customer who signs with the company receives every year a new mobile phone when giving the old one up. This kind of contract has been widely used by mobile telephone companies, but not by mobile phones producers. Products recovery activities (such as scrapping campaigns), were seen by OEMs as a way to attract new customers without considering any residual value of the recovered phone.

Despite all these difficulties, OEMs are taking an increasingly active role in secondary markets and remanufacturing. Several companies as *General Electric*, *Boeing*, *Caterpillar*, *Xerox*, *Kodak*, *Deere*, *Navistar*, *HP* and *Pitney Bowes*, have obtained great advantages adopting such policies, improving their public image and profits.

7 Conclusions and future developments

In this paper, we assessed the profitability for OEMs that remanufacture returned products to supply secondary markets with high quality returns.

Basing on the logical model of a hybrid remanufacturing system proposed in a previous work by Behret and Korugan [2], we evaluated the effects of secondary markets on system's performance.

An experimental approach based on DOE, simulation modeling, and ANOVA analysis has been presented.

The study is based on data obtained by means of a careful and critical analysis of the existing literature on remanufacturing systems.

We showed that OEMs may have some convenience in supplying a secondary market with high quality returns. OEMs can increase secondary market profitability acting on return rate, return mix quality and system average capacity utilization rate.

We also evaluated, in different operating conditions, the secondary market influence on primary market service level and on minimum selling price on the secondary market.

Further developments would concern the impact on profit when selling price changes both on the primary and on the secondary market and the organization of the productive system in order to properly manage the new demand.

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