Abstract: The synergic action of different actors involved in environmental protection, is pushing more and more companies to adapt and, in some cases, to revolutionize their strategies, plans and their business goals in an "environmentally conscious" way. It is crucial, therefore, to develop and adopt suitable production techniques and EOL management policies for products. Product recovery involves concepts like reuse, remanufacturing and recycling. In many cases, moreover, reuse and remanufacturing could be simultaneously implemented if secondary market supplying is a profitable option. When hybrid remanufacturing/manufacturing systems (HRMSs) are implemented and when secondary markets are supplied with high quality returns, some new issues have to be faced and these systems have to be deeply analyzed to better manage them. With this aim three different policies to supply a secondary market will be compared (two PUSH policies and one PULL policy), which are based upon different stock level control.

Key-Words: Sustainable Manufacturing, Remanufacturing, tactical analysis, Secondary Markets, Inventory Control, Computer Simulation

1 Introduction

The increasing rate of products' technological innovation is pushing towards new profit models, based on an integrated management of product life cycle. Innovative policies intended to the recovery of end of life products, in fact, not only improve the efficiency in natural resources consumption, but also open new business opportunities for producers [6]. Among the different recovery options, remanufacturing is of particular importance and is worthwhile of interest [9].

The aim of this work is to investigate the multifaceted field of remanufacturing and to identify those factors make it a sustainable business from a financial point of view. The operating cost of a remanufacturing system, in fact, is strictly linked both to strategic decisions (logistics network configuration, secondary markets opportunities, prices of new and remanufactured products, design of new generation products) and to tactical and operational decisions [1].

Products at the end of their life cycle can be recovered in many ways and with different levels of efficiency. The option of materials recycling is at the lowest level of recovery efficiency, this process allows to retrieve the raw material but not the added value of the product. Higher added-value recovery options are: reconditioning, remanufacturing or cannibalization, where are retrieved, respectively, products, modules or components. Recovery options like repair or reuse don't involve massive restoring activities [11].

The simultaneous presence of returns with a high residual value and demand for such products on secondary markets, puts the management in front of the dilemma to allocate these units to the secondary market rather than to remanufacture them and supply the primary market.

In an our previous analysis ([3]) we have assessed the convenience of supplying a secondary market considering some factors related to reverse logistics system (r), to the product (quality mix) and to the market (price). Being such factors external to the system, the analysis has to be considered from a "strategic" point of view. If supplying a secondary market is a profitable option, the production system has to be reorganized in order to best manage this new demand, determining the most suitable operating rules to be used. To this aim three stock level control strategies for secondary market supplying will be compared: the first two are based upon a PUSH logic and the last upon a PULL logic.

This paper is organized as follows. In the problem setting section the stock level control strategies and the logical model used are presented. In Section 3 some issues about the comparison of the different policies are discussed and the results are presented. Section 4 summarizes our findings and draw the conclusions.

2 Problem setting

Many studies confirm that the increased uncertainty and variability in a remanufacturing system makes problematic the use of traditional tools for production planning and control [5].

An important difference between the production planning in traditional systems and in remanufacturing systems is that in the latter disappear the typical hierarchical relationship between the canonical stages of production planning.
The actual production volume, in fact, besides being dependent on market demand and production capacity constraints, depends also on the amount of materials (core, parts and components recovered, new components) that become available or necessary during the production process.

Hence, a proper production planning and control in remanufacturing systems (capacity planning, scheduling, monitoring the progress of orders, etc.) is strongly influenced by a sound planning and control of the recovered materials.

In remanufacturing systems a number of randomness related to the quantity, quality and timing of products or components recoverable, makes the definition of a good stock control policy more difficult [2].

In Hybrid Manufacturing/Remanufacturing Systems literature comparisons between PUSH and PULL policies are usually performed but such policies typically control manufacturing orders release [8].

In particular adopting the PUSH policy all returns are remanufactured as soon as possible (as soon as a batch of returns is available), while in the PULL policy returns are remanufactured as late as possible (remanufacturable returns are hold until the stock level of the finished product warehouse drops below a specific value).

All things considered, the choice is between remanufacturing or retain a core stock and then remanufacture them later. In these cases, the adoption of a PULL policy is due to the core holding cost increase as remanufacturing process flows by: it could be desirable retaining cores in the upstream warehouses to cut holding costs. In this way finished products stock is reduced but delays and stock out risk increases. Some interesting results are proposed by van Deer Laan, Salomon, Dekker and van Wassenhove ([12]): as the difference between cores and finished products holding costs increases, the PULL strategy becomes more and more attractive. If these costs are equal (an unrealistic assumption) is better to use a PUSH strategy.

### 2.2 Logical model

We have considered the same multi stage inventory control model used in [3], but some features of the secondary market and the cost structure are quite different (fig.1). Even though the secondary market on average is able to absorb the share of high-quality products not used by the primary market (working hypothesis in [3]), it is necessary, in this case, to model the secondary market demand, taking into account the time between two subsequent requests in the secondary market. Therefore, we have introduced in the model a warehouse of high quality returns for the secondary market in order to meet demand from such market when it occurs. Such demand is modelled by a Poisson process with parameter $\gamma_{SM} = \gamma \gamma$ (see [3] for more details). Being such value the overall high quality returns fraction, on average the secondary market could be able to absorb all high quality returns.

The holding costs for the secondary market buffer are calculated using the "traditional method" [10]. Unlike the primary market, we don’t consider backordered or lost sales on the secondary market.

Moreover to evaluate the effectiveness of the different policies considered, the holding costs are “amplified” in such a way their influence on overall costs is about 15% on average. This increase, in fact, makes more evident the impact of the control policies on the system operation.

**2.1 Stock level control strategies**

In the following analysis the performances of three different stock level control strategies for secondary market supplying will be compared, namely: PUSH policy, PUSH 2 policy and PULL policy.

In particular, the PUSH policy optimizes, in a specific time horizon, the percentage of high quality returns with which the secondary market will be supplied. This policy doesn’t consider the warehouses’ stock level in the system when an high quality return occurs, but, it pushes the product, with a certain probability ($K_{PUSH}$), or into the warehouse specifically intended for secondary market supplying or into the remanufacturing process.

The PUSH 2 policy works like a disposal policy for returns in excess. A maximum value ($K_2$) for high quality returns (buffer 2) is defined and when it is exceed products are moved into the warehouse for secondary market supplying. So, without considering the other stock levels, the system pushes the high quality returns which exceed the above mentioned upper limit.

In the PULL policy, when an high quality return occurs, a control on the finished product stock level is carried out. Until this level is less than a specific threshold ($K_{PULL}$) the product is remanufactured, otherwise it is sold on the secondary market.

The product is “pulled” by the finished product warehouse intended for primary market supplying. $K_{PUSH}$ and $K_{PULL}$ values are considered for optimizing the objective function which will be conceived as a profit function taking into account both secondary market supplying opportunities and backorders or delayed orders on the primary market.
3 Results and discussion

3.1 Priority rules performance comparison for PUSH 2 strategy

The performance of the PUSH 2 control policy is affected by the specific priority rule adopted in the remanufacturing process. In particular, the remanufacturing process is fed by three different buffers containing high, medium and low quality cores and the choice about the first among these type of core to be remanufactured affects the way the secondary market is supplied with respect to:

- the number of units received in the warehouse intended for secondary market supplying;
- the time between two subsequent sales in the secondary market.

Therefore, to effectively compare the above mentioned policies performance, it is required to carefully choose among the various priority rules the one that allows the PUSH 2 control policy to work as efficiently as possible.

As concern returns management policies comparison, for the PUSH 2 policy, the priority rule which best performs according to return rate changes will be considered (Table 1).

Table 1: Adopted Priority Rule for PUSH 2 Policy

<table>
<thead>
<tr>
<th>Return Rate</th>
<th>Priority Rule</th>
</tr>
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<tbody>
<tr>
<td>0.7</td>
<td>2, 1, 3</td>
</tr>
<tr>
<td>0.8</td>
<td>2, 1, 3</td>
</tr>
<tr>
<td>0.9</td>
<td>2, 3, 1</td>
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</tbody>
</table>

3.2 Secondary market supplying policies performance comparison

Figure 2 summarizes the results obtained comparing the different secondary market supplying policies considered. The PULL policy is the best one, while the PUSH policy performs the worst.

Figure 2: Policies Performance Comparison

Comparing PULL and PUSH policies it can be noticed that making the most of the information about finished products stock level, the PULL policy performs better in supplying the primary market by reducing the average waiting time of backorder sales (Figure 3, Figure 5) and the number of delayed sales (Figure 4, Figure 6). This reduction is really outstanding because of high backorder costs and loss of public image risks.

Moreover, the PULL policy supplies the secondary market with a larger amount of products (Figure 4, Figure 6) although the waiting time in the finished products store is significantly higher (Figure 3, Figure 5). However, the increased revenues from secondary market sales cover the increased holding costs. The PULL strategy, therefore, performs better in secondary markets managing.
PUSH 2 and PULL policies have a quite similar performance with regard to the primary market, while PUSH 2 policy has poor performance in secondary market management, as the number of sales (and hence the revenue) is significantly lower than in other control policies (Figure 7). This result shows the difficulties of PUSH 2 policy in managing secondary market.

The highest profit is achieved by the PULL policy while the PUSH 2 policy gets the lowest cost (Figure 8). The PUSH strategy while getting higher revenues than the PULL one, achieves the lowest profit because of the highest cost.
It can be noticed that adopting the PUSH 2 policy the secondary market is fed with smaller quantities of high quality cores and so less products are manufactured (manufacturing costs are lower) and holding cost are lower (high returns holding cost is lower than manufactured products holding cost). Moreover, remanufacturing costs are slightly higher than those incurred with other control strategies because high quality returns have low remanufacturing costs. So the PUSH 2 policy has the lowest operating costs. The PUSH and PULL strategies have a quite similar cost structure, the main difference concerns the high backorder costs incurred with the PUSH strategy.

4 Conclusions

In this paper, three returns management policies for secondary market supplying in Hybrid Manufacturing/Remanufacturing Systems are proposed, which are based upon different stock level control.

Particularly, PUSH 2 control policy performance is affected by the specific priority rule adopted in the remanufacturing process and so, to effectively compare different policies performance, an analysis is made to carefully choose the rule which allows the PUSH 2 control policy to work as efficiently as possible.

Summarizing, the PULL policy analyzes the inventory level of the warehouse intended for supplying the primary market and decides on a case by case basis how to use high quality returns. In this way the PULL policy allows for an improved system processes visibility: finished products stock level has an impact on workstations and upstream buffers state. The PUSH policy is "myopic": it doesn’t care about system buffer state but high quality cores are a priori used for the primary or secondary market.

The PUSH 2 policy is a middle way solution, it has a "partial" insight of the system, high quality cores are used according to only the stock level of a certain buffer. So, as information quality increases, system performance increases too.

Note that even if the PULL policy economic advantages are noticeable, its implementation is more difficult from an organizational point of view because stocks cannot be independently controlled. So, according to the specific case, some decisions must be taken considering the trade-off between economic benefits and organizational difficulties.

References:


